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O'Connor, Henry

Gas manufacture and lighting.

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ROYAL SCOTTISH SOCIETY OF ARTS
KEITH LECTURES, 1909

GAS MANUFACTURE AND LIGHTING

BY

HENRY O'CONNOR
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n.d.

from Engineering Physics Dept.

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OFFICE OF THE "JOURNAL OF GAS LIGHTING"
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GAS MANUFACTURE AND LIGHTING

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KEITH LECTURES, 1909

GAS MANUFACTURE AND LIGHTING

A COURSE OF FIVE LECTURES

DELIVERED BY

HENRY O'CONNOR

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LONDON
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GAS MANUFACTURE AND LIGHTING

CHAPTER I

The history of lighting—Puirmen—Lamps—Cruisies—Candles—Early gas lights—Early electric lights—Coal: its formation, products, derivatives, suitability for gas-making.

THE first form of lighting was no doubt the wood fire, kindled partly for warmth and partly for lighting. When a light was required away from the fire, what was more natural than for a brand to be plucked from it and carried in the hand? Then followed the holder for such a brand. The origin of the name of "Puirman" for the candle-holders was told by Mr. D. Bruce Peebles, a former President of this Society, in his presidential address in 1887, as follows:—

"Before they came into use in the country districts it was the duty of the herd-boy to hold the fir candle at supper-time, so that the farmer and the farm-servants might see the road from the food to their mouths. After they had all got their supper it was then the duty of the farmer—so the tale goes—to hold the fir candle and let the boy get his supper; then, if light was wanted through the evening, of course the boy had to resume the duty of candle-holder. When a beggar arrived at a farm town about sundown the farmer was expected to give him his supper and a night's lodging in the barn, besides his breakfast in the morning to speed him on his wanderings. Now, as a *quid pro quo*, the beggar or puir man had to give his service and hold the fir candle, paying proper attention to keeping it in good condition by taking off the ash, or, to use the Aberdeenshire phrase, 'snitting the candle.' This custom being established, the beggar or puir man got associated, in the minds of the people he called on, with the duty he had to perform—namely, the holding of the fir candle—and he (the candle-holder) came at last to be spoken of as the puir man, the name being associated with the work he did; so thus it was that, when the iron fir-candle holder was invented, it was called a puir man or 'peer man.'"

An early application of electricity to the making of light was discovered by Davy in 1810; but it was not until 1844 that Foucault introduced it into our scientific laboratories. I well remember the lighting of the Thames Embankment by the Jablochkoff candle, as it was called, and the Brush lights in 1878, and in 1881 when Edison and Swan introduced the incandescent type of burner. This, at the time, caused a panic among gas proprietors; but this panic has died down, and the value of gas shares has never been higher than at the present time.

The name "gas" is probably of Dutch origin, as it was Van Helmont who, in 1610, discovered that aëriform bodies existed other than the atmosphere, and he called these "gas." But it was left for Dr. Clayton in 1690 to produce gas distilled from coal in a retort. This he termed "spirit," which burned on a light being applied. In 1774 the French chemist Lavoisier invented the gas-holder; but this was not made public in England until 1789. We next come to the first practical scheme of lighting, which was introduced by William Murdoch in 1792, when he lighted his house and premises at Redruth in Cornwall with gas. Five years later he lighted up some buildings in Old Cumnock, Ayrshire, and a year after that the works of Boulton & Watt at

Soho, Birmingham. Ten years after Murdoch's practical experiment in Cornwall, Lebon, a French engineer, gave the first public display of gas-lighting in France, he also having lighted his house in Paris with this illuminant. January of 1804 saw the arrival of Winsor, who delivered many lectures which helped to bring forward the merits of gas-lighting. He, however, had only a very superficial knowledge of his subject, and many of his statements were erroneous. However, there is no doubt that to him is due largely the beginning of the London Gas Companies, more especially that huge concern now known as the Gas Light & Coke Company. Murdoch read papers before the Royal Society of London, and was awarded the Society's gold medal. He was also the inventor of the first motor-car. From about 1812 onwards gas companies were started in many parts of the country, until now almost every village even can boast of its gas manufactory. It might be interesting to mention that the Edinburgh Gas Company was established in 1817 with a Mr. Grafton as its consulting engineer.

The first gas pipes were fixed some distance from the walls of the houses, as architects insisted that they must be hot.

When the first gas-holders were put up, they had to be enclosed in houses, and one of such houses is still to be found at Musselburgh Gas Works with the beams inside for the counterbalance weights, although it is now used as a coal store. The Royal Society of London recommended that these gas-holders should be limited in size to 6000 cub. ft. (they are now made as big as 12,500,000 cub. ft.). It was tried to convince these worthy scientists that there was no danger, by making a hole in the side of a gas-holder and lighting the issuing gas; and although no explosion occurred, they were still opposed to any increase in size.

Coal, of course, is the foundation of gas manufacture It would perhaps be well if we start this part of the subject at the commencement—namely, at the time when the coal was beginning to be formed; but I would remind you that we are not talking of yesterday or the day before, but of thousands or even millions of years back. There are two branches of science which know no finality, and these are Geology and Astronomy—times in these sciences go far beyond human comprehension. It can be easily understood, therefore, that the origin of coal is lost in some obscurity. On the age of coal one author has said: "*Every tree and plant, whose ruins are compressed into the coal we use, was ante-paradisiacal—was green and was wood centuries upon centuries before Eden had her first rose and Eve her first walk amidst admired and admiring flowers.*" Coal does not belong to one era, as it is found in all sedimentary formations. It may be said to have been formed by the action of water and air on dead vegetable matter, probably by a process of fermentation. Perhaps the best illustration of the process will be obtained if we consider the decay of herbaceous matter in marshy soils, when a humus is formed which is commonly called peat. That the vegetable matter was of a very huge nature there is no doubt, from the remains of tree-ferns of a gigantic size and from the thickness of the beds of coal. The primæval forests were no doubt to some extent like the tropical jungles, but there is evidence that a warm humid atmosphere abounded, which greatly assisted the growth of all vegetation.

Decomposition of coal is continually going on, and gases are eliminated from it. Especially is this so where the younger coals are found, as in Germany, where brown coal or lignite is more readily mined. Here the springs of water are usually found to be highly charged with CO_2. In the floors or strata upon which the coal rests, a peculiar fossil vegetable is found, called Stigmariæ. These at first were thought to be a separate plant, but are now considered to be the roots of sagillaria. The horizontal extent of some seams of coal is much greater than that of others, but all have what is called underclay of arenaceous shale, from which firebricks can be made. If coal were not mined in the dark in this country, many most interesting fossil remains would come to hand. It has been suggested that the difference in the varieties of coal is due to an original difference in the plants from which they were derived. The mud, silt, and sand which formed the roof and flooring of the seams when the upheaval took place which placed the coal underground, are now turned into schist, shale, and stone by the superincumbent pressure. The sequence of formation of a normal coal seam has been described as follows: (1) The outspreading of sand or gravel with drifted plant remains followed by shale as the currents lost velocity. (2) The gradual retreat of the water, leaving the surface open to the air. (3) The deposition of very fine sediments. (4) The rooting of vegetation in the deposit so formed, in which mass were caught wind-borne vegetable dust and floating vegetation. The very huge pressure which has been exerted by the earth in the formation of the coal since the upheaval, the heat of the earth at the depth where the coal was formed, and water, have each had something to do in the making of what we now call coal. That pressure and temperature have had much to do with the decomposition of the ancient submerged vegetation, and therefore with the preparation of coal, is proved by the following experiment. If a piece of wood be placed in a steam-boiler and subjected to a temperature of about 350° F., which equals about 120 lb. per square inch, or say 9 atmospheres, it will be found to be converted into a species of coal. Another curious instance of the conversion of wood into coal was found out when a pig swallowed a piece of wood and retained it in the stomach, which finally caused its death. This had then very much the appearance of petrified wood.

No doubt, in the course of thousands of years, the peaty mass of vegetation will have given up hydrogen and oxygen, and some kind of lignite or shale has been formed; these in time becoming the various qualities of coal up to anthracite, according to their age and to the pressure of the earth above them and the water percolating through. The change may be supposed to have taken place in the following order: woody fibre to peat, then to lignite and earthy coal, thence to cannel coal, house coal, and then to anthracite; the transformation resembling the change when wood becomes charcoal, but without the loss of all the H and O. The following table shows the chemical composition of the various substances just mentioned, and indicates clearly the loss of the H and O and the consequent increase in the proportion of C.

	Percentage.		Composition.
	C	H	O and N
Woody fibre . . .	52·65	5·25	42·10
Peat (from the Shannon) .	60·02	5·88	34·10
Lignite (from Cologne) .	66·96	5·24	27·76
Earthy coal (from Dax) .	74·20	5·89	19·90
Cannel coal (from Wigan) .	85·81	5·85	8·34
Newcastle coal (Hartley) .	88·42	5·61	5·97
Welsh anthracite . .	94·05	3·38	2·57

From the above percentages the ash has been deducted.

The more modern the formation, the less carbon and more hydrogen. The table also explains another reason why coal differs in various parts of Great Britain. If we deduct from the composition of wood 3 equivalents of marsh gas (CH_4), 3 of water (H_2O), and 9 of carbon dioxide (CO_2), we have the constituents left of Newcastle splint coals. On this account Liebig, the famous chemist, considered that the wood had given off these gases in its transition to coal. I have a number of samples of these different coals on the table, most of which have been lent me by Messrs. Waldie & Son. However coal was made, whether by the carbonisation of wood or by the action of water, it has proved itself to be one of the most indestructible of known substances. You may like to know of what the ash mentioned in the table consists. An average sample may be taken as giving an analysis as follows:—

Silica	15·48
Alumina	5·28
Peroxide of iron	74·02
Lime	2·26
Magnesia	0·26
Potash	0·53
Soda	a trace
Sulphate of lime	2·17
Total	100·00

It has been suggested that cannel coal is only clay impregnated with oil under great pressure. Shale coals are highly fossiliferous and contain fish remains. The later formations of coal may be said to have been already partly gasified and to have thrown off their volatile matter. The material thus more nearly resembles coke.

The last three of the above classes are usually divided into four groups—say cannel, semi-bituminous, bituminous, and anthracite. The next shows their average composition. The variations from the former table are accounted for by the inclusion of the ash in the second analysis.

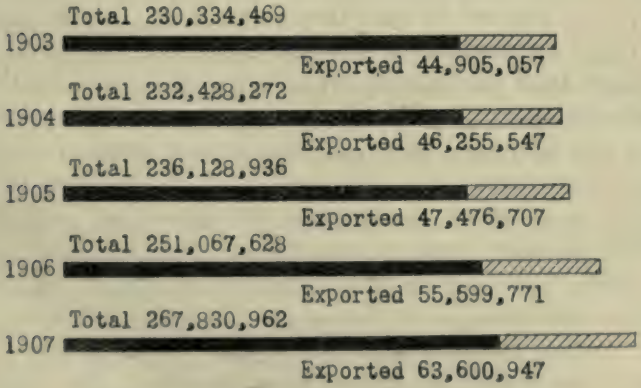
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Cannel	64·5	8·25	9·0	1·0	1·0	16·25
Semi-bituminous	77·3	5·2	12·0	1·9	0·6	3·0
Bituminous	80·0	5·9	9·0	2·05	1·05	2·0
Anthracite	89·97	2·5	2·5	0·5	0·8	4·0

The ash is of course really a useless part of the coal, as it gives out no heat and has to be heated by the remainder of the material. On this account, cannel is not so much good as a fuel. In the anthracite the hydrogen and oxygen have already combined to form water. Coal contains many elements beyond those already enumerated above, such as iron, lime, silica, alumina, magnesia, and traces of potash, soda, chlorine, and iodine. An exact analysis of coal is therefore a somewhat complex matter.

The sulphur, apart from its unpleasant odour, will cause the formation of clinker in furnaces, and therefore the less of this the better. Anthracite is of course the best coal for heating purposes, ranking as 100 to 73 against cannel. The weight of coal as against water is as 1·3 to 1. This is called its specific gravity. You will not want me to tell you that coal has a black colour; you know this perfectly well. But perhaps you did not know that when it is broken, it assumes a cubic or rhombo-prismoidal form, lamellar in one or sometimes two directions. The coal strata were no doubt originally deposited in horizontal or nearly horizontal positions; but, curiously enough, all, or nearly all, have assumed basin-shaped formations with long and sloping sides dipping down to a common and profound centre. Speaking of the basin which extends around the neighbourhood of Newcastle, Sunderland may be taken as the centre and lowest part of it, and the sides "crop out" or come to the surface of the earth, or nearly so, all around that point. The north edge is at the Coquet or Northumbrian Stream; the south edge or rim of the basin is in the valley of the River Tees, dividing the counties of York and Durham; the west rim is 20 miles west of Newcastle; and the east edge is somewhere out under the sea in the German Ocean, and at present useless.

We are so accustomed in this country to going underground and mining there to find our coal, that it will be unknown to many that coal has been quarried in the same way as stone within recent years at St. Etienne in the department of the Loire, France. At that place it has outcropped or come to the surface. The ancient Britons obtained all their coals in this way; in fact, there are many evidences in Scotland that this was the only known method years ago of getting coal. There is no doubt at the present time a greater area of workable coal known in Great Britain than was the case fifty years ago; and it is highly probable that fifty years hence this area will be still further increased, despite the coal to be mined during that half-century. As showing the various reports made by different authorities on the probable continuance of coal, a Mr. Thomas S. Peckston, R.N., a civil engineer, writing in 1819, when from the Register the total annual consumption of coals from Newcastle and Sunderland was about 3,105,000 tons, computed that the mines were capable of supplying 1,115,136,000 tons, and that this would serve for 359 years, whereas this amount would only last, at present rates of consumption, some four or five years. Passing to more recent times and to higher authorities, a Royal Commission, which finished its five years' labours in 1871, reported that they considered that in all there were, at depths not exceeding 4000 ft., say 90,207,000,000 tons in known coal-fields, and 56,273,000,000 tons in concealed coal-fields, or a total of 146,480,000,000 tons in Great Britain.

The Royal Commission of 1905, however, reports that down to a depth of 4000 ft., and including all seams one foot and more thick, the available quantity in proved coal-fields in the United Kingdom is 100,915,000,000 tons, or 10,707,000,000 tons more than estimated in 1871, although 6,000,000,000 tons have been used in the thirty-three years. If all the coal burned in the United Kingdom during 1907 were divided equally among



Coal Raised in Great Britain.

the population, each individual's share would be 4·142 tons.

The coal output of Great Britain in 1898 was 202,045,000 tons, and this rose to 267,830,962 tons in 1907. Of these amounts the quantity used in Great Britain was 154,788,000 tons in 1898, and this followed the increase in the output to 1907, when the home consumption was 204,230,000 tons. Thus while the home consumption in 1898 was 76·6 per cent. of the total output, this in 1907 was 76·3 per cent. Looking at this from another point of view, in 1898 was exported 47,257,000 tons, and this increased until, in 1907, 63,601,000 tons went abroad. The question of the taxation of export coal is a vexed one, but it would seem that if our coal be not sold now, while we have the market abroad, new coal-fields may be found and machinery devised for working them in the foreign countries, so that the market will leave Great Britain and the money at present coming into British hands will be lost. Should we not better "gather our hay while the sun shines"? Exported coal brings money to this country, not only for the working of the coal, but also by freight, railway carriages, etc. The miners are certainly not working as hard as formerly, as is shown by the number of tons they are now bringing up. During 1899 they each brought up an average of 385 tons, whereas in 1901 they only raised 344 tons each. In Great Britain, as stated, we use about four tons per head of population per annum, not of course merely for heating and cooking purposes, but for gas, power, and the thousand and one purposes for which coal is now used. London alone uses about 15¾ million tons, of which about one-third would be used in gas-making. Of these 15¾ millions, about one-half would go there by sea and the other half by rail. Canals carry very little coal to that great city. There are some 700 to 800,000 men employed in mining the coal in Great Britain, and it may be here remarked that this country produces about one-third the world's supply of that most useful commodity. It may be asked why the depth of a coal-mine is limited, but when it is known that there is now thought to be no doubt of the existence in this globe of ours of a central heat, it will be more readily understood. At a depth under the surface of about 20 ft. the thermometer is perfectly stationary, not being affected by the changes of the seasons; but at greater depths the temperature progressively rises. It has been found that the thermometer rises about 1° F. for every fifteen to twenty yards descended. This is of course not the case where the mine is ventilated, nor would it be right to take the temperature when men were at work, as the heat and exhalations from their bodies would influence the heat thus obtained. At the greatest depth ever bored, namely, 6570 ft., the rise of temperature was found to equal 1° F. for every 62·1 ft. The deepest mine in Great Britain is at the Pendleton Colliery near Manchester, which is 3470 ft. below the surface; but at the Calumet and Heckla mine, Lake Superior, there is a shaft 4900 ft. deep which would give a rise of 78° to 79° F., or say 138° F., truly a terrible and trying heat in which to ask any men to work. Mining is not now the terribly dangerous work it once was, although from time to time we hear of very disastrous accidents. Returns show that while the deaths from coal-mining were nineteen per million tons worked in 1851, they have been reduced to only four per million tons in 1900.

Machines for coal-cutting are largely in use in America, but are only being gradually and slowly adopted in this country. Machines require a good roof, a moderate inclination of seam, and a field of coal free from faults; they are therefore more advantageous in thin seams and hard coal. Manual labour, which can the more easily adapt itself to the conditions of the mine, and which conditions vary continually, will not be ousted for a long time, if ever. Most of the machines are driven either by compressed air or electric motors. Perhaps it may be asked how coal is first found. Primarily the strata of the ground is examined, and when the various layers that always accompany coal are noticed in the neighbourhood, a series of bore holes are made, with a number of tools which not only cut a long narrow tunnel into the ground, but also bring to the surface the earth or rocks encountered. When a great depth has to be bored to, it is customary to employ a steam boring machine.

In 1841 the methods of lifting both the coal and the men and women—for at that time a very large number of women were employed in mines—were very crude; in fact, the windlass was quite common, and the men and women coming to the surface were merely seated in what was called the clatch iron. As soon as they arrived at the top, the handle was made fast by a bolt drawn from the upright post; the hand was grasped, and by main force they were brought to *terra firma*. It is recorded that one Daniel Pellatt was once drawn over the roller and killed, by falling from the top to the bottom of the shaft, by his own uncle and grandfather, whose attention was diverted by a passing funeral just as their unfortunate relative had been drawn to the pit mouth. From a sketch of a girl who worked in a pit in those days, it can be seen that Lady Harbarton's rational costume was adopted by them; in fact, it is stated that there was no difference either in costume or work to be done between the men and women. As contrasted with the hand labour for raising the coal from the mine, the present-day machinery is very far advanced. The fastest speed I know of is 1776 ft. in 45 seconds, or an average rate of nearly 40 ft. per second. Boys of course were employed in the old days in all parts of the mine from a very early age, both below and above ground. In some collieries it was a boy who watched the engines; in fact, the great George Stephenson commenced life as such an attendant of the drawing apparatus for a coal-mine.

Of the large amount of machinery about the pit's mouth, I need hardly speak here, but of one piece I may say that the coal-washing apparatus has removed some 20 per cent. of ash and 1·2 per cent. of free dirt from the slack, rendering the latter much more useful for heating purposes.

Up to 1799, only 103 years ago, the miners of Scotland were serfs of the soil, liable to apprehension as thieves and vagabonds if they went from one place to another, had to receive a discharge from one coal-master before they could be taken on by another, and bartered between the masters just as ponies and other material about the mines. In fact, it is on record that a young coal-master, visiting a friend's colliery, recognised the voice of a miner, showing him round, as the same as those of the men of his own colliery, and he asked the miner how he came there. He replied, "Do you no' ken me? It's me yer faither swopped for a pony." The pay at that time was regulated by Act of Parliament at £1, 2s. per annum. What would the miners say to such wages now?

At this time I might perhaps profitably touch upon a few historical points connected with coal. This most useful commodity was first introduced into London, but by the advice of a medical council, the King (Edward I.) forbade its use on account of the smoke it created. It still I fear makes a great deal of smoke in that city, but I fancy the present King George would hardly have power to forbid the taking to London and use there of the 15¾ million tons that are consumed annually. In 1300, despite the prohibition, coal began to be employed in London in the arts and manufactures. Sixteen years later the King (Edward II.) was again approached, this time by Parliament, to prohibit the use of coal, and a proclamation to that effect was issued; but after a time, owing to the high price of wood, coal became tolerated. It was not, however, until more than two centuries later, in 1560, that the use of coal was at all general for domestic purposes. Subsequently to this date special licences were granted to various persons, giving them the exclusive privilege to smelt iron, make "alom tarre," "charcole," etc., from "seacole," as it was termed, on account of its being transported by sea.

After these few brief historical notes, we may turn to some of the uses and abuses of coal. The value of coal for heating purposes is usually gauged by an instrument known as a calorimeter. This was originally designed by a Mr. Lewis Thompson. In it every atom of heat is absorbed by the water. From this it will be found that about an average of 14 to 15 lb. of water can be evaporated from 212° by the combustion of 1 lb. of coal, although in practice this will be brought down to only about 10 to 11 lb. water owing to absorption and radiation. The unit of heat in this country is the B.Th.U., or British Thermal Unit, and is that amount of heat which will raise 1 lb. of pure water 1° F. from 39·1° to 40·1°. If then we wish to know the number of B.Th.U.'s per 100 lb. of coal, we can obtain it without a calorimeter if we know the chemical analysis of the coal. We multiply the percentage of carbon by 14,220 B.Th.U. (this equals the number of B.Th.U. per lb. carbon), and the percentage of hydrogen by 60,854 B.Th.U. (the number of B.Th.U.'s per lb. hydrogen), deducting oxidised hydrogen (this equals the percentage of oxygen divided by 8), also deduct for latent heat of steam (this equals the percentage of hydrogen multiplied by 9 plus the moisture) and multiply this latter by 946. This equals B.Th.U. absorbed per unit of water during the conversion into steam, and we thus get the total B.Th.U. per 100 lb. coal.

The carbon in coal is in two forms—fixed and volatile. The former remains in the coke while the latter combines with hydrogen to form compounds called collectively "hydrocarbons," the principal of which are marsh gas (CH_4), acetylene (C_2H_2), ethylene or olefiant gas (C_2H_4), propylene (C_3H_6), and butylene (C_4H_8). There are in all about 12 gallons of moisture in a ton of coals, possibly not as absolute water, but which will be formed by the union of the oxygen and hydrogen in the coal under the influence of heat. It is the unoxidised portion of the hydrogen in the coals which shows its suitability for gas-making. Eight parts by weight of oxygen require 1 part of hydrogen to form water (H_2O), by volume 2 parts hydrogen and 1 part oxygen. Of the sulphur in coal, say about

13·8 lb. per ton, some 6·53 lb. are left in the coke, while 7·27 lb. pass off with the gas.

Average coal has a total heat of combustion per 1 lb. of 14,700 B.Th.U. and an equivalent evaporative power from and at 212° F. of 15·22 lb. of water. Of this heat on an average some 47 per cent. only is utilised in ordinary heating boilers, the remainder being lost through imperfect combustion, radiation, and other causes. In 1872 the average consumption of coal per HP. per hour in steamers was 2·11 lb., but in 1901 this had been lowered to 1·48 lb. This shows a considerable improvement in these boilers, but what of the land boilers? Do they equally share in this improvement? It is to be feared not. Many most useless boilers and engines are wasting the coal which has helped to bring about the prosperity of this country. This is shameful, is it not? But what about the coal fire at home in our houses in the ordinary grate; are they doing anything to save the waste of coal? Alas! they are far behind even the old boilers just referred to. The heat of an ordinary coal fire is about 2400° F. in the hottest part. Of the total heat of combustion in an ordinary open grate coal fire 43 per cent. is carried up the chimney, 42 per cent. is radiated and conducted and absorbed by the walls, and 15 per cent. is lost by radiation and conduction externally and by imperfection of combustion. Coal in such a grate uses 2099 cub. ft. air per 1 lb. of coal, of which only 7 per cent. is used in the products of combustion; with a gas stove, however, less than 10 per cent. of the heat generated is wasted up the chimney.

1 lb. coal will generate enough heat to raise 14,700 lb. water 1° F.
1 lb. coal will evaporate say 10 lb. water at 212° F. in a boiler.
1 lb. coal will generate, say, 4½ cub. ft. of gas.
1 lb. coal requires 300 cub. ft. air at 620° F. for its combustion.
1 lb. coal is said to give off ¾ oz. of soot in ordinary fires.
1 lb. coal will generate about ½ horse-power.
1 lb. coal will lift, say, 16,500 lb. 1 ft. high per hour.
1 lb. coal will lift 1 lb., say, 16,500 ft. per hour.

To illustrate the wasteful use of coal in our houses it may be mentioned that it takes about 4¼ lb. of coal to boil 1 gallon of water in a copper kettle starting from cold, while a joint of beef weighing about 12½ lb. requires about 17 lb. coal to cook it in two hours. Of course it is the smoke which is given off from our household fires which is a great source of loss; and when we consider that smoke destroys animal and vegetable life, injures the sight, nerves, and general health, lowers the moral tone of the people, kills valuable plants by covering them with poisonous slime and by choking up the pores of leaves so that they cannot imbibe the moisture they require, it decays public buildings, destroys works of art—in fact, it has been computed that London alone spends over £5,000,000 annually through smoke—it will be seen that there is another reason beside the saving of coal why we should try and use our coal more scientifically. It is computed that one-half the smoke is attributable to private fires and the other to those of the various factories. In stoking a fire, whether it be in our house or in a factory, we should go upon the principle of putting on little and often. If we put on a quantity at one time we shall at once find dense smoke issuing from the chimney; this smoke is soot, and soot is carbon, one of the heat-giving elements in coal.

One of the most important residuals, from an economical point of view, is the ammonia which has been washed out of the gas. This is now usually made into sulphate of ammonia, which would have been better named "nitrate of sulphur," or given some other title which would have indicated to the farmer that it contained the nitrogen which he knows is what he requires; and when he finds a substance to his hand called "nitrate of soda," he concludes that it is better than "sulphate of ammonia," which does not contain the blessed name of "nitrogen" or "nitrate." As a matter of fact, the latter contains 20 per cent. of nitrogen, while the former only contains 15 per cent. Of the total nitrogen in the coal, amounting perhaps to 2 per cent. or 45 lb., some 15 per cent. will come away as ammonia, 1½ per cent. as cyanogen, 35 per cent. will be free in the gas and combined with the tar, and 48½ per cent. will remain in the coke and thus be wasted. Numerous suggestions have been made for utilising this nitrogen, but without particular success. It is, however, with the 15 per cent. which comes away as ammoniacal liquor with which we have to deal, and this is converted either into concentrated liquor ammonia or into sulphate of ammonia by heating the liquor and so driving off the alkaline vapour, which is made to pass through a solution of sulphuric acid, when a salt is formed which is the sulphate of ammonia. This is roughly the process; but there are many refinements which serve to increase the quantity of sulphate produced and to reduce the cost of its manufacture. The ammonia in the liquor is usually combined with some of the acids from the gas such as H_2S and CO_2, which are free, and with small quantities of chloride, thio-cyanate, sulphate, thio-sulphate, and ferrocyanide, which latter are all fixed, or, in other words, will not pass off by heating. For their removal, then, the liquor is first treated with lime or caustic soda, for which these acids have a great affinity, and thus the ammonia is rendered free and will pass off when heated into the sulphuric acid.

A simple plant is one where the still contains a number of trays over which the liquor passes downwards and steam is admitted at the bottom, and this passes upwards, heating the liquor and driving off the ammonia to the saturator containing the sulphuric acid. The waste gases from there, still hot, pass to the heater; and these serve to partially heat the liquor before it is forced by gravity (the tank supplying it being overhead) to the still. There is also a lime-mixer with an agitator, actuated by hand, and a pump to force the lime water into the still. The partially condensed gases from the heater pass to a condenser and scrubber, and thence through a seal pot to the oxide purifier, as they will contain a proportion of H_2S

driven off by the heat in the still. The crystals of the sulphate are fished out of the saturator with a perforated ladle and laid on the draining table to take off the acid before the sulphate is placed in the store, when the final draining takes place. Some plants employ steam to lift the sulphate from the saturator, others provide a door at the bottom of a hopper-shaped saturator through which the sulphate can be removed from time to time. A recent patent employs stoneware for the saturator in place of thick lead. There are many other minor refinements, but these can hardly be detailed here. To obtain the "white" sulphate, generally preferred, acid made from brimstone, and not what is known as pyrites acid, should be used.

An average analysis of tar would consist of the following :—

Carbon	81·43 per cent.
Hydrogen	6·83 ,,
Nitrogen	0·94 ,,
Sulphur	0·52 ,,
Oxygen	10·28 ,,

This, when subjected to fractional distillation in a still made of iron to contain several hundred gallons, is then heated to 212° F. by means of a steam coil. The distillation is usually divided into—

Ammoniacal liquor	4·8 per cent.
1st light oils	3·0 ,,
2nd ,, ,, ...	4·6 ,,
Creosote oils	18·6 ,,
Anthracene	10·2 ,,
Pitch	58·8 ,,

This is done by gradually increasing the temperature of distillation. The light oils are those having a less specific gravity than water. The products of such distillation may be expressed in another way according to the actual marketable constituents from one ton of tar, as—

Ammoniacal liquor	5 gals.
Benzol	6 „
Naphtha	3 „
Carbolic acid	3 „
Creosote oils	55 „
Anthracene	32 lb.
Naphthalene	128 „
Pitch	12¼ cwt.

The heavy oil is used for lubricating purposes, and can be further divided into a purer lubricating oil, a lamp oil or paraffin. The aniline ($C_{12}H_7N$) is also obtained from the heavy oil by distillation after agitation with hydrochloric acid and supersaturation with milk of lime. It is then saturated with hydrochloric acid, decomposed by an alkali and subjected to another distillation, purified, and aniline is formed.

A description of some of the derivatives from tar may prove interesting.

Benzene (C_6H_6) was first eliminated from coal tar in 1845 by A. S. Hoffman and Charles Mansfield,who prepared it in quantity in Hoffman's laboratory. The latter also discovered toluene (C_7H_8) in 1848. Benzene and toluene yield many properties, notably the well-known aniline whence the numerous dyes are obtained, also gluside, commonly known as saccharine, which is used extensively as a substitute for sugar in diabetes, hepatic diseases, and corpulence. Saccharine is 450 times sweeter than sugar.

Phenol (C_6H_5OH) (carbolic acid) was discovered by Runge in 1834, and its preparation from coal tar engaged the attention of many eminent men of science about that time. This phenol and creosote ($C_{12}H_{20}$) form the basis of valuable antiseptic and disinfectant preparations, and the first named is also the source of the dye aurine.

Naphtha (C_5H_{10}) is used as a rubber solvent.

Naphthalene ($C_{10}H_8$) was first discovered by Garden in 1820; and this yields vermillene, scarlet, and naphthol yellow.

Anthracene ($C_{14}H_{10}$) was discovered by Dumas and

Laurent in 1832, and prepared from coal tar in 1857 by Fritsche. This substance in 1868 was found to give on treatment alizarene, or artificial madder, from which a great number of beautiful dyes are produced; it is, in fact, the most beautiful as well as the most valuable of the tar products. (Take a small quantity of the muddy-looking alizarene, as much as will go on a shilling, and place it in a glass beaker (4 in. diameter, 6 in. high) half-full of lukewarm water; boil the dye, and then introduce a piece of calico mordanted with various mordants which have not appreciably coloured the cloth. This will now become dyed various colours in a few minutes.)

We have proof that the Egyptians knew of some such method of mordanting cloth, for we read in Pliny's *Hist. Nat.*, xxxv. 11, the following: "There exists in Egypt a wonderful method of dyeing. The white cloth is stained in various places, not with dye-stuffs but with substances which have the property of absorbing colours. These applications are not visible upon the cloth, but when they are dipped in a hot cauldron of the dye they are drawn out an instant after dyed. The remarkable circumstance is that though there be only one dye in the vat, yet different colours appear upon the cloth, nor can the colours be afterwards removed."

Xylene (C_8H_{10}) was discovered in coal tar by Ritthausen and Church, and Jacobsen in 1877 isolated the three xylenes.

Picric acid ($C_6H_2(NO_2)_3OH$), used extensively in the manufacture of lyddite and is to-day very profitably sold, and is sometimes used to colour beer, but has such a colouring power that white wool dipped in beer containing it will be dyed yellow.

Pitch. Something like 50 per cent. of ordinary tar is pitch, the great bulk of which is used for briquettes of fuel making, by mixture with small coal. The development of this particular trade is truly wonderful. Twenty years ago the industry was small, whereas to-day the annual output of briquette fuel made with pitch is upwards of four million tons. Pitch enjoys the distinction of being the only tar product which is not produced in excess of its requirements.

Tar oils. Millions of gallons are used annually as fuel, and for protecting wood, preparing lubricants, and lighting open spaces in special lamps (such as the Wells and the Lucigen) now extensively employed.

Ammonia, which is used extensively for medicinal and many other purposes.

Aniline ($C_6H_5H_2N$), the parent of the coal tar dyes, was discovered as a coal tar constituent by Runge in 1834. The aniline as in crude coal tar, however, was never found in sufficient quantities for commercial use. Runge first obtained brilliant colouring matters by the action of chloride of lime on aniline, but it was left for a young chemist, who was working in London, trying to prepare quinine artificially, using aniline as his base, to discover arichine. This young chemist is now Sir W. H. Perkins; the dye was called Perkins' Mauve (coal tar dye), and was patented in the autumn of 1856. He failed to manage the quinine substitute, but this has since been found, and will be mentioned later. The enthusiasm for the coal tar colours has never abated, until to enumerate those now derived from tar would occupy four pages of foolscap. [Experiment: Take with a glass rod a small quantity of the ordinary violet aniline, dip the rod into a beaker of water, and hold the latter against a light or white paper, to show the brilliant colour and the great strength of the dye.]

From the tar, from 1 ton of coals, 10 lb. of various chemicals usable for dyeing purposes (not 10 lb. of dye-stuff), as the initial sources of dye-stuffs, will be obtained. Sir A. Roscoe states that 1 lb. weight of cannel coal will produce sufficient dyes to colour the following lengths of flannel ¾ yd. wide:—

2 ft. violet.
5 ft. yellow.
8 in. magenta.
3½ ft. scarlet.
2 in. orange.
4 in. turkey red.

When we consider that so much can be done from 1 lb. cannel coal, and remember that the world's gross output of coal is about 200,000,000 tons annually, the enormous resources of coal tar as a source of dye-stuffs is at once apparent. About 2000 coal tar colours are on the market.

The coal tar colour industry is now almost entirely in the hands of the Germans. At the Industrial Census of 1895 there were in Germany almost 12,000 men directly engaged in working up the coal tar derivatives. The growth of the exports of these from Germany is worth noting.

In 1883 it was 8,490 tons, costing 1⅛ million sterling.
In 1890 „ 19,016 „ „ 2¼ „ „
In 1898 „ 41,393 „ „ 5½ „ „

Between the coal tar dyes and painters' paints there is a great gulf fixed; the coal tar colours being clear soluble solutions which will never have a sediment, and the painters' colours being opaque colours, the minerals from which they are produced settling to the bottom. Dyes are colours in solution, pigments are colours in suspension.

Aniline colours are now universally employed in staining tissue for detection of disease, and also for microscopic work. Some bacilli are sensitive only to one colour—blue—which is therefore the means of their detection.

Fluorescine is applied in finding whether water from one source has any possible underground connection with other sources of water; a very small quantity serving to colour an immense quantity of the water.

Methyl-orange is a coal tar colour used as an indicator of acid or alkali.

As before mentioned, substitutes for quinine to be made from tar have been found. In fact, a long list of antipyretics and analgesics are now found in the extra Pharmacopœia, such as acetanilide, ammonol, antinervin, monobromacetanilide, acetophenone, anthrarobin, banzanilide, chinolinum, exalgin, gallanol, kryofin, lactophenin malakine, neurodin, phenacetin, phenazone or antipyrine, and its compounds pyoktanin and thermodin.

It is interesting to note that several of the large German aniline dye houses, such as Farbenfabriken, vorm. F. Bayer & Co., Farbwerke Meister Lucius and Brüning, and others, now run pharmaceutical departments for the manufacture of such drugs as phenacetin, etc., on a very large scale. Twenty years ago they simply made aniline dyes in which they still do a very large trade with the East. I have to thank Messrs. J. Ross & Co., of Falkirk, for lending me the many samples of tar and ammoniacal liquor products.

I hope you may, none of you, need to obtain a closer acquaintance with any of these medicines, but I think I have said enough to show that there are more things in coal tar than were dreamt of in the philosophy of many.

CHAPTER II

The gas works—The engineering of a modern gas works—Apparatus necessary—Modern machinery—Horizontal, sloping, and vertical retorts—Mechanical stokers—Condensers—Scrubbers—Washers—Purifiers—Gasholders.

IN choosing the site for a gas works, naturally, the proximity to railway, canal, or river is the first consideration, so that the large amount of material which has to be brought to and taken away from the gas works can be economically handled; but it is also an advantage to have the gas works at the lowest part of the district to be supplied, as the gas, having to ascend, will gain in pressure to the extent of $\frac{1}{10}$th of an inch of water for each 10 ft. rise above the works. In these days of incandescent lighting, where high pressures are an advantage, this point is of considerable importance, as such pressure is obtained without any mechanical aids. Again, there is a further point to be considered, and that is the nature of the subsoil of the site of the proposed gas works. I have known works where the foundations for buildings had to be carried 30 ft. below the ground level before a solid bottom was obtained, and to carry piers of concrete to this depth necessitated their being about 10 ft. by 8 ft. across, so that the earth could be removed from the excavation. For smaller buildings piles were used of both wood and iron, but the expense of such foundations is very heavy—in fact, it has been said frequently that as much was spent below ground as above it. The question of the depth at which a solid foundation can be found is also a very important one when the gasholder tank is considered, as also the presence or absence of water in the soil; and further, if gravel or sand are to be found, this may be economically employed in the building of the works.

Before detailing the building of the works, it might be well to simply describe the course of the gas from retort to gasholder. The coal is put into the retorts, which are heated from the outside, the gas is given off and passes into the hydraulic main, thence to the condensers or coolers for removal of tar, through which, and from the retorts, it is pulled by the exhauster and forced through first the washers and the scrubbers for removal of ammonia, thence to purifiers for removal of CO_2, H_2S, and CS_2, and through station meter to gasholder.

The first point in the arrangement of a gas works is the means for bringing the coals to the coal store and retort house. When it is considered that there is one works where the quantity of coal will amount to nearly 1,500,000 tons per annum, it can be understood that this is a most important part, as on the economical conveyance of the coal will depend the cost of the gas. The methods employed vary from the cart and horse, bringing the coal direct from the mine to the gas works, to huge steamers conveying thousands of tons to piers jutting out from the gas works, such as the two at Beckton, the second of which was erected under my superintendence and was 342 ft. from the face of the embankment and measured 713 ft. long at the T head, and was able to accommodate five colliers at once. The first method requires no description, but the method adopted in India of tipping the cart at the base of a heap and then loading small baskets, which are carried on the heads of men and women up slopes leading to the top of the heap of coals, might be said to be the most primitive. Of course wherever possible the coal should be brought into the coal store or retort house as high as can be above ground level so as to avoid hand-lifting. An excellent method of unloading ships or barges, and which was adopted on the piers just mentioned, is by means of Hone's patent grab, which is worked with a single chain from the crane. The grab is opened and allowed to fall upon the coals; the tightening of the chain closes the jaws of the grab and encloses the coal within same. The usual size of these grabs is to contain one ton of coals. This is then lifted and swung over the wagon or hopper to be filled, and the upper portion is lifted through a ring, hanging from the end of the crane at a suitable height, and the portion which is passed through the ring is provided with a trigger, and when this trigger comes in contact with the ring, as the grab is lowered over the wagon, it automatically opens the grab and allows the coal to fall out. There are other types of these grabs, such as the one supplied by Applebys with the Temperley transporter, which latter is a huge T-shaped structure with one end of the T hanging over the ship and the other running away inland over the coal heaps or trucks, having one or more of these grabs lifting the coal out of the ship and then transporting it along the upper arms of the T. Sometimes the elevator is arranged to be lowered into the ship or barge. This coal can then of course be deposited into the hopper of an elevator or conveyor of any of the usual types, such as the Band Conveyor, the Push-Plate Conveyor, or the Gravity Bucket Conveyor. The latter is perhaps the best for general purposes, as it can be carried at any angle or vertical or horizontal, and forms an elevator and conveyor combined in one, and the coal having once been filled into the buckets is conveyed away direct to the place required, without being shifted or broken up. Wherever coal has to be elevated by a crane, or any intermittent work of this kind carried on, it is usually best to employ hydraulic power; as there can thus be in the accumulator a reserve of power, which is stored up during the time the machinery is idle. With separate boilers and engines on each crane, each one has to be of the full capacity for the maximum amount of work. The hydraulic plant working the cranes, etc., on the two piers at Beckton has a 17-in. accumulator with

17-ft. stroke with three sets of compound engines with cylinders 14 in. diameter and 24 in. diameter by 21 in. working at 130 lb. per square inch and giving a hydraulic pressure of 750 lb. per square inch. This is conveyed to the two piers by 6-in. pressure pipes, and the water, after use, is returned to the pumps by 9-in. pipes. The unloading capacity at this works is some 14,000 tons per day. The trucks usually employed for conveying the coal are provided with hopper bottoms and movable doors underneath, working by rack and pinion, of some five to eight tons capacity, but of course if there are no locomotives at the works they have to be smaller. At the Beckton Works there are over 50 locomotives of the full 4 ft. 8½ in. gauge, and some 60 miles of railway, a large portion of which is some 30 ft. above the ground level. As this is the standard gauge for all railways in Great Britain, it is advisable, when laying down railways in a gas works, to adopt this gauge rather than any smaller one, so that, if required, ordinary railway trucks can be taken about on the gas works lines. Hydraulic or electric capstans are very useful and can be recommended, and especially in works where there is no need of a locomotive. The advantage of these is that they are ready at any moment, and that when not in use are not costing anything for upkeep.

As regards the coal stores, these must be of such capacity as will provide coals during stoppages in supply due perhaps to strikes at mines or on railways, or frost or snow. The usual average is about seven weeks' supply at the period of maximum make. Where hand-charging is in use, the coal stores are best placed on each side of the retort house; but where conveyors and hoppers are in use, the ends of the retort house will generally form the best position. The remarks of Professor Lewes at the Society of Arts in London, some years back, may, with advantage, be repeated:—

"A coal store should be well roofed in and have an iron floor bedded in cement; all supports passing through and in contact with the coal should be of iron or brick; if hollow iron supports are used, they should be made solid with cement. Under no condition must a steam or exhaust pipe or flue be allowed in or near any wall of the store, nor must the store be within 20 ft. of any boiler, furnace, or bench of retorts."

Where machinery is used for stoking retorts, the coal has usually to be broken into, preferably, small lumps, and for this purpose a coal-breaker with rotating claws is generally employed.

The drawing shown illustrates a complete double-pair claw coal-breaker of a medium type and also several of the claw pieces for fitting to the two shafts. The breaker may be elevated on a frame and fitted with automatic feeder and screen and driven by an electric motor. Two sets such as the one shown are installed at the Paisley Gas Works.

Where the railway is brought direct into the works and is on the ground level, a method of tipping the wagon is frequently provided, the wagon having an end door. The tipper is fixed between the railway lines close to the receiving hopper of a coal-breaking plant. The lifting frame, which is guided on each side by steel uprights, engages with the rear axle of the wagon, and is raised by means of hoist chains and barrel. The gearing is fixed on one of the side plates, the worm-gear running in an oil bath, and may be driven either by belts from a driving shaft connected with the plant or by an independent motor.

We now come to the methods employed of filling the retorts with the necessary coal, and before describing the machinery employed it will be necessary to first of all refer to the hand charging and drawing, although this more properly belongs to the manufacturing portion of the gas works, which is the subject of the next lecture. The charging and the drawing of retorts by hand and also the clinkering is not a very delightful job, as the men have to work in the steam from the coke, as it is being quenched, and in the smoke from the coal and tarry matters around the mouthpieces. Several forms of hand-charging machines have been invented, one of the earliest being that of West. In this instance a hopper was provided on a travelling frame and a short double scoop was filled with coals and pushed into the retorts on rollers, emptied by turning the handle, withdrawn, refilled from the hopper, and again run into the retort, emptied, and withdrawn. This can all be done by one man. As regards the drawing, a travelling stand fitted with rollers allows the rake to be run easily in and out of the retort, and thus saves considerable work. Another form is the one devised by Messrs. Biggs, Wall, & Co. In this case two men are usually required. A scoop which is of the ordinary size and shape is filled and brought up on a barrow, and is then lifted by a differential pulley block carried on an overhead gantry on the tramway. When on a level with the mouthpiece, the scoop is pushed forward, when the pulley travels along the overhead gantry and runs into the retort. Owing to its travel along the gantry, the work is comparatively light. Arrangements are made for rapidly lowering the scoop, by throwing the differential action out of gear. Besides the manual charging and drawing machines already mentioned, Messrs. West have also designed numerous power-driven charging and drawing machines, one of which consists of a scoop driven by compressed air. This power also serves for propelling the machine along the floor and raising or lowering the scoop to the desired height. A similar type of machine is also provided for the drawing of the retorts. As of recent times the projection of the coals by rotary motion has come into use, this firm has also designed such a machine driven by electrical power as is also the ram-discharging machine which removes the coke from a 20-ft. retort by pushing it from one end.

The late Mr. William Foulis of Glasgow was a great believer in the use of hydraulic power for the charging and discharging of retorts, and he first of all designed his drawing machine, in which the handle of the rake was a hydraulic ram and in which the raising of the rake so that it could pass over the coals also opened the valve and projected the rake into the retort. When the rake-head was pressed down into the coke, it altered the valve and caused the rake to be withdrawn. This gentleman, in conjunction with Sir William Arrol, later patented what is known as the " Arrol-Foulis " charging machine, and this consists of a pusher which is forced into the retort to a certain distance each stroke, pushing not more than a fixed quantity of coal, which is delivered from a measuring chamber. In this way, although the charge is made up of a number of small quantities, the layer of coal is of a very even thickness. The arrangement of stops which regulates the varying length of travel of the pusher is very ingenious.

The de Brouwer machine receives the coal between a wheel having a concave groove on its periphery and a moving band, and in this manner imparts motion to the coal which is projected into the retort, the speed of wheel and band being varied according to the distance the coal has to be driven into the retort.

The first type of this projector was suspended from an overhead travelling carriage and fitted with a telescopic shoot and tun-dish to receive the coal from continuous overhead measuring chamber.

Another form of D.B. retort charging machine is suspended in a travelling frame, and fitted with power travelling and hoisting gear, and a coal hopper.

Again, the D.B. patent charging machines are suspended in a travelling frame with power travelling and hoisting gear and a 5-ton hopper. The machine working at the Lower Sydenham Gas Works of the South Suburban Gas Company is charging 260 yds. 20 ft. through retorts, which are arranged in five tiers. Then the D.B. patent retort charging machine can be suspended in a travelling frame with power travelling and hoisting gear, and fitted with a 5-ton coal hopper and an elevator which raises the coal from the floor level, the coal falling by gravitation from the store through openings provided at suitable intervals along the retort house.

Of comparatively recent times is the system of utilising the natural sliding of the coals to carry them into the retorts. This natural angle is 30° with the horizon, and a number of these sloping retorts have been adopted in many works, and we have a very excellent example of this system in this city. The coal is usually delivered to overhead hoppers, from whence it is fed to a shot pouch measuring chamber and thence through a telescopic chute to the retorts on the various levels. By regulating the speed at which the coal leaves the chute, a very even layer of coal can be assured in the retort; and, when the coal has been carbonised, the coke only requires a small amount of inducing to cause it to slide out at the lower ends of the retorts. It will be seen that there is a very small amount of manual labour required with this system, and hence its popularity. Both the horizontal and sloping retort systems require that a space should be left above the coals to permit of the passage of the gas, and hence the retorts are only about half-filled; and to utilise this space a patent has been taken out by the late Engineer of the Guildford Gas Works to set the retorts at an angle of 45°, at which angle of course the coke will slide out of itself. However, still more recently the use of vertical retorts, which have long been used in the shale oil works, especially in this neighbourhood, have been tried in this country and abroad, where some thirty works have adopted them. The systems tried vary principally in respect of the filling of this retort, some preferring the periodic, and others the continuous supply of the coal in small quantities and similar removal of the coke. By the former method the retort is filled up with coal, which remains in the retort for a period of twelve hours, and is then completely emptied. Thus the mass of unconsumed or partly unconsumed coal, through which the gas evolved from the coal has to pass, varies throughout the period of the charge. In the latter, as exemplified by the Woodall & Duckham system, the space above the coal is constant, as is also the depth of unconsumed and partly consumed coal; the coal is continuously being fed into the top of the retort, and the coke again being continuously removed at the bottom. Formerly all the coke had to be drawn through a water-seal, but now the drum system has been adopted, and this is revolved occasionally and the coke removed through it. This improves the quality of the coke. These retorts can be fixed in the open if required, and it is evident that the area of ground covered by plant for a given make of gas will be much smaller than where horizontal or sloping retorts are in use.

In this way a very large quantity of gas can be made from the ton of coal—as much as 14,165 cub. ft. of 14·16-candle gas per ton—and an increased quantity of tar and ammonia, the latter amounting to some 25 per cent., with an improved quality of coke. A large installation of the latter system has recently been decided upon for the Burnley Gas Works. There is little doubt that one or other of these vertical retort systems will be largely used in the larger gas works in future. Another plan which seems likely to be adopted now that heating power and not light is being required, is to use the ovens which are at present being used for making foundry coke from slack coal. These ovens are usually in batteries of fifty; each retort being 33 ft. long, 6 ft. high, and 18 in. average width, and holding 6 tons net. These retorts are open at both ends and have luted doors.

The coal is charged into these through three or more charging holes in the roof of the oven and then levelled and the doors luted. The gas escapes through a rising pipe and main. The hydraulic form is not generally in use. The gas made during the first half of the charge is rich, but is poorer during the second half, when it is only of some 560 B.Th.U. per cubic foot. This latter portion is first freed from its bye-products, and then burned through tuyères with hot air, supplied by a fan, the heat passing up each side of the oven and over the top, and then to regenerators for heating the air. Regular heating is required with such retorts, and the charge works off in about twenty-four to thirty hours, and the coke is then pushed out mechanically and quenched as it leaves the oven.

The removal of the coke from the retort house, after it had been drawn from the retorts, was usually done by means of barrows, either containing the hot coke, or, if the coke was quenched with water in the retort house, then the barrow was used to remove it cold; it was then run out to the heap, tipped alongside, and then lifted by means of a shovel. This is of course a very primitive way of working, and is still in use in all but the largest gas works; but the introduction first of stage floor houses, where the coke is made to pass down chutes to the floor below, and of machinery of all kinds, and the invention of the hot-coke conveyors, has enabled these latter to carry out this part of the work mechanically.

The modern types of hot-coke conveyor consist generally of a trough with bars across same, which are moved forward by means of chains or links drawing with them the hot coke. The arrangement of these conveyors varies, in some cases having the chain or links in the middle, and in others having them at the side. The trough is frequently made of cast-iron, with renewable chain slides and side liners.

In some coke storage yards the coke conveyor brings the coke out from the retort house, and delivers it by means of long chutes on to the coke heap; these chutes being designed of such an angle that the coke glides gently down. The coke may also be delivered into the storage hoppers over sloping screens which extract the breeze.

Sometimes the coke is delivered to the outside of the retort house and there shot into skips or small trucks which are afterwards raised by crane into the coal store or into hoppers, from which buckets can be filled and raised by travelling crane to the heap in the coke yard.

Sometimes these hoppers are placed sufficiently high to enable carts to pass underneath them. A long-armed jib radiating close to the retort house is also sometimes used for distributing coke among the various hoppers. In the gas works in this city the hot-coke conveyors travel straight out into the yard up an incline into hoppers for the various-sized cokes, from which railway wagons can be loaded, or, if desired, carried on to a higher point for distributing the coke on to heaps.

The plant installed at the Paisley Corporation Gas Works for handling coke consists of a Temperley transporter, having two electric trolley hoists, which consists of an elevated steel track about 409 ft. long, supported by eighteen steel frames and forming a curve. The two electric trolley hoists run on this track, and each has a capacity suitable for lifting a skip containing about 12 cwt. of coke at a speed of 60 ft. per minute, and transporting this load at a speed of 500 to 600 ft. per minute. Each hoist is fitted with a single motor of the totally enclosed series wound type, as well as the necessary controllers, resistances, etc., all operations being conducted from the driver's cab. The coke is conveyed in automatic dumping skips suspended from patent automatic dumping fall blocks, thereby providing for the discharge of the skips at any desired height.

In regard to these transporters the engineer writes—

"The skips contain each about 14 cwt. Skip and coke 20 cwt. This load can be elevated, conveyed to screening plant, and returned, in all 114 ft., and lowered to starting-point, in 60 seconds. Each elevator and grab is easily capable of handling about 30 tons per hour. Our present requirements, however, are about five tons per hour only; and at this rate of working our cost of handling averages 1¾d. per ton. Wear and tear oncosts are very small, and I have every reason to be satisfied with the plant."

When dealing with the class of coal obtainable generally in Scotland, the coke does not agglutinate as it does in England, consequently it is in small lumps; but in England the coke comes out in huge masses, so that it is impossible to use it for domestic purposes until it has been broken, and for this purpose a number of machines have been designed to reduce the size of the coke without making too much dust. One of the earliest and most successful of these was the Thomas & Somerville patent, in which the coke passed between two toothed rollers, these teeth being set like a worm so that the coke would be drawn in. Another form is a number of discs of conical pointed teeth, these points being made of chilled cast-iron and consequently very hard. These coke-breakers are usually accompanied with a screen on to which the coke falls as it passes through to separate the large and small, and sometimes a structure is made by which the coke is elevated and broken, and then the two sizes of material delivered into carts or other receptacles, or from the screens into hoppers for filling wagons.

The exhauster which draws the gas through the plant already described, and forces it through the remaining piece of apparatus, will be described fully in the next lecture.

The condensers used for cooling the gas and removing the tar are of many types, some consisting of a number of horizontal pipes laid so that any tar and water deposit in them shall flow to a seal pot and thence to the tar tank, others having pipes vertically fixed above a box for the collecting of these impurities. The more recent types favoured are what are known as the "Annular" condensers. These are formed of two wrought-iron tubes, one inside the other, the gas passing between the two tubes, while the air can circulate round the outside tube and also pass up the centre tube, which, owing to the heat of the gas, forms a species of chimney, and thereby draws in air at a good rate. This system also permits of regulation by the closing off of the centre portion of the tubes, so that the area exposed can be regulated according to the quantity and temperature of the gases being made.

Sometimes—and this is especially advantageous in hot climates—a spray of water is used over the top of the condenser, so that, by the evaporation of this water, heat can be drawn from the condenser. Other types of condensers are formed by laying pipes under water; others again pass the gas in thin layers between plates or through pipes, the other sides of the plates or pipes being under water.

For the final removal of the tar an ingenious piece of apparatus has been used in France for many years and has of recent years been adopted in this country. It is known as the "Pelouze & Audouin" condenser, and consists of a vertical inlet pipe surrounded by liquid, and over this inlet pipe is a cap or holder of sheet-iron with a number of vertical slots in the side of same. Outside this again is a further holder attached to the first containing a number of holes drilled in vertical lines. These holes are so placed that they do not come opposite the slots so that the gas passing through the slots strikes against the solid portion of the outer tank, and then the gas has to return and pass out by the holes. So as to prevent a great rise in pressure when a large quantity of gas has to pass through the condenser, the gasholder is balanced; and should the inlet pressure increase owing to the number of slots above the liquid being too small for the quantity, then the holder rises out of the liquid and exposes a greater number of slots and holes through which the gas can pass. The pressure inside therefore governs the area of the holes through which the gas has to pass.

The next piece of apparatus which we have to consider is the washer. There are many types of this in use, but in all the gas is made to pass below the water, and through small holes or slots, and in bubbling through the liquid makes it foam, until the gas has to pass through a species of mist, and is thus submitted to the washing effect of the liquid, and gives up to it any tar that may be left in the gas and a proportion of the ammonia and then some of the CO_2 and H_2S.

The scrubber is another piece of the plant which is for the same purpose and consists of a cast or wrought iron cylinder of a height of say five or six times the diameter. The gas enters at the bottom and passes up through a number of grids formed of ½-in. boards on edge ½ in. apart, each layer being set to cross the previous one. Water is run in at the top and sprayed over the grids, so that they are all thoroughly wetted, and the gas being divided up into streams, and being broken up at each layer of grids, has a large wetted surface offered to it, which allows the water to attract the ammonia out of the gas. Formerly these scrubbers were filled with coke, but if any tar came forward to them it quickly closed up the pores of the coke, and then the surface offered was much reduced; with the boards, however, the surface becomes slippery, so that any tar falls quickly to the bottom and runs away with the liquor to the wells. The boards also offer 233 per cent. more surface than the coke even when the latter is new. The scrubbers are sometimes fitted with washers at their lower end, so that the gas passes through these first, and for small works this saves the separate washer. The scrubbers are usually put up in pairs, and sometimes have galleries at the top and spiral staircases fitted; the water being supplied through an automatic tipper, so as to ensure a rush of water to form a good spray.

The origin of the name "scrubber" may probably be attributed to the apparatus invented by the late Mr. George Anderson called the "Brush Scrubber," in which brushes rotated, one above the other, partially immersed in water, and the gas travelled through the bristles in the opposite direction to the movement of the brushes. There are several modern forms of rotary scrubbers which are now generally called "washer scrubbers," in which a number of rotary brushes or bundles of sheets are fastened to the shaft and made to revolve also partially immersed in liquid, the gas passing through each circular brush or set of bundles in turn. As each brush is in a separate compartment, the water is made to flow from one to another, and so get strengthened as it nears the end where the gas enters.

As regards the purifiers, these are rectangular boxes usually from 5 ft. to 6 ft. deep, and formerly the covers were made with sides which dipped into lutes, cast all round the side of the purifier proper. These covers when of a large size are elaborately braced structures and covered with sheet-iron, and for the lifting of these, travelling gantries, either running on girders fixed to the walls of the house or with sides to obtain the necessary height, so that the rails could be on a level with the purifiers, were usually fitted. Hand and hydraulic power have both been used for the lifting of these covers. Hydraulic power has frequently been obtained by the use of a small pump worked by a lever. When these covers are a considerable weight, this arrangement, although slow, enables the covers to be lifted even by a single man. The more recent type, which is commonly known as "Green's Purifier Cover," has saved a great deal of labour in the removing of the covers, as these are divided into small sections, and in place of the lute, the joint, with the purifier plates, is made with an india-rubber strip. The Hovey Patent Lifting Crane is made to run above the top of the purifier and to raise Green's Purifier Cover and carry it away, and this without need of any superstructure.

For the removal, filling, and emptying of the material required for the purifiers, in place of the old wheelbarrow system, the Temperley transporter has been adopted at Paisley. In this instance two tracks of rolled H section girders run the whole length of each bay of the conveyor house. These tracks are carried on steel frames bolted to the roof girders and side walls, and each carries an electric trolley hoist generally similar to those on the coke transporter, already described, but modified to suit the restricted headroom.

The system of three-floor purifier houses is to be advocated, as the upper floor will make a good mixing place for lime or oxide, to which it can be carried by elevators, and spread by conveyors, and dropped into the purifiers on the second floor through canvas chutes. When the purifier has to be emptied, doors on the under side of same can be opened and the material emptied through these into trucks on the ground floor. In this way, the least possible amount of handling by manual labour is obtained.

At the Granton Gas Works, elevators have been arranged for filling and emptying the purifiers, so that the discharging and manipulating of the material in every conceivable way is carried out mechanically.

The station meter is an enlarged meter of the wet type, such as is still seen in some consumers' premises, but of course has to be built of stronger materials, and the interior of the moving portion or drum has to be filled with a strong angle iron and tied frame. The speed at which these meters revolve is an exceedingly slow one, only amounting to about 1⅔ revolutions per minute. This is probably due to the fact that nearly double the water has to be passed into and out of the drum portion, during the passage of any given quantity of gas, and this, being incompressible, is naturally a somewhat slow process. The size of such station meters in large works is considerable. The three which measure the gas at the Provan Gas Works in Glasgow measure 23 ft. 9 in. × 19 ft. × 17 ft. high.

The gasholder, which is often called a "gasometer" by the general public, is probably the part of the gas works upon which the greatest amount of engineering has been expended, as the structure is of such a complex type, that it is almost impossible to calculate out the stresses to an exact extent. The holder in its simplest form is merely an inverted cup rising and falling in a tank of water and guided by rollers running on columns. As the cup rises out of the water, the water of course keeps the gas from leaking out from the inside of the cup. Where a large quantity of gas has to be stored, the use of the single lift holder would entail the digging of a very deep tank, as of course the tank must be the full depth of the holder; consequently a means of telescoping the holder has been adopted, and in one case—and this that of the largest holder in the world, containing some 12,500,000 cub. ft.—there are six lifts or lengths, telescoping one within the other, when the gasholder is in the tank. In this way the tank has only to be about ⅛th the total height of the holder. To prevent the gas leaking, between the different lifts, a water seal is provided, and this is formed by means of a cup or turned-up groove all round the bottom of the one lift and a turned-down groove or grip on the next outer lift. As the inner lift comes out of the water, the cup is filled, and the grip of the outer lift is caught by the cup on the next inner lift and is immersed in the water in the cup. The pressure of the gas inside the holder pressing against the top of the inner lift raises it, and with it the other lifts as they come out of the water. The modern gasholder tank is usually excavated below the ground level and formed with walls of concrete, sometimes backed with puddle and in other cases rendered on the inside face with cement. The inside is generally not completely excavated, but is left with what is termed a "dumpling" in the middle. This saves a considerable amount of excavating and also reduces the quantity of water. This "dumpling" is also usually covered with a cement facing, and where the top of the gasholder is untrussed this "dumpling" forms the base of a complete framework of wood upon which the crown sheets rest when the holder is right down. This framework has the appearance of the ribs of a gigantic umbrella with a considerable amount of cross bracing. Where the ground will not permit of excavation, the tank may be made of steel plates riveted together and fixed wholly or partly above the ground, but in that case some means would be required for keeping the water in the tank from freezing into a solid mass and so preventing the moving up and down of the holder.

To return to the holder proper, the columns or standards which are fixed around the holder for guiding are of two forms of construction. The older-fashioned may be spoken of as the "Multipost" type, as each column has to resist by itself the stresses put upon it by the wind, etc., without assistance from its neighbours, whereas in the more modern type of construction, which is due to the late Sir George Livesey, we have a completely braced and tied cylindrical cantilever structure, in which the stress upon each standard is spread over a large number of the neighbouring standards and thence to the diagonal bracing and to the ground. This has considerably reduced the weight of metal in the framework and rendered possible the gigantic holders of recent times. Another improvement also due to Sir George was the carrying of the inner lift or lifts above the framework when the holder was fully inflated, he having proved that the weight of the outer lifts, hanging like a curtain all round the inner ones, was sufficient to prevent the latter from coming out of the perpendicular even under the severest wind stresses. This arrangement led to the invention of a number of different methods of guiding holders, which obviated the use of the columns or standards altogether. The two principal forms which have survived are the spiral guided gasholders patented by Gadd & Mason and the wire rope system of Pease. The former supplies a number of guides of a spiral form either fixed in the tank or upon the sides of the lifts and gearing. With these guides are carriages containing wheels one on each side of the guide; thus the holder in rising and falling twists around in the tank, and owing to the spiral shape of the guides cannot be forced out of the vertical. The simplest way to understand the principle of this type of holder is to consider the tank as a huge nut and the guides therein the threads of same. The bolt may be considered the holder, but in place of the threads upon this, rollers are provided inside. The other form consists of a wire rope, fastened to the upper end of the holder or lift at one side, carried beneath rollers at the edge of the tank, around to the opposite side of the holder, then over a further roller and attached to the bottom of the holder or lift. This arrangement is repeated a number of times around the holder. When any overturning action takes place owing to wind or snow, etc., the holder tends to turn about a point on the water line and directly under the centre; consequently the one side must rise and the other fall. If we can imagine the side where the rope is fastened to the top as rising, this will draw up the wire rope with it, and following the course of the rope we shall see that the effect at the other end of same is to draw up the point where the rope is attached to the bottom, immediately opposite; so that if the side nearest the wind tends to rise, the pull of the rope tends also to raise the opposite side, whereas if the holder is to tilt this opposite side would have to come downwards, consequently the holder must remain upright. Both these forms of columnless gasholders have proved themselves thoroughly satisfactory and safe, even in the heaviest gales. The calculation of the stresses in the cantilever type of holder is a very difficult one, but the writings of Mr. Southwell Cripps have put this on a comparatively simple basis, which, however, is too long to enter into here.

CHAPTER III

The making of the gas — Gaseous firing of retorts—Open-hearth furnaces—Purification—Composition of gas at each stage of the operations — Recovery of the nitrogen — Heat losses — Retort-house governor—Enrichment by cannel coal.

THE importance of the gas industry can be perhaps best expressed by stating the quantity of coal used annually, in Great Britain alone, for the manufacture of gas for heating and lighting. This, at the present time, is some 15 million tons. The process involved consists of the distillation of the coal by heat, while solid carbon and ash remain in the form of coke. Roughly speaking, the products of such distillation are as follows:—

Gas, 10,000 cub. ft., or 17 per cent.
Tar, 10 gals., or 5·1 per cent.
Virgin ammoniacal liquors, 7·9 per cent., or say 28 gals. of 10 oz. strength.
Coke, 70 per cent., or 1540 lb.

The heating of gas retorts has been the special study of gas engineers from the time gas was first made. In the early days, and in fact up to about thirty years ago, all retorts were heated on what is known as the open-hearth system, which is simply a large furnace under the retorts which is open to receive all the air the chimney can draw through the fuel. This is the most wasteful way of obtaining heat for such a purpose; not only because the heat is generated in the furnace and not among the retorts, but also because the amount of air drawn in and necessary to ensure complete combustion of the fuel, and having to be heated, is fully double that actually required according to the composition of the fuel. Over 50 per cent. of the heat evolved by the fuel is carried up the chimney in this way.

It was due to Sir Wm. Siemens that the modern system of gaseous firing, with its regenerative chambers, utilising the heat of the waste gases, was introduced and is now almost universal. In this system the air drawn into the furnace is regulated so that only sufficient is taken in under the bars to convert the C to CO. As a matter of fact, there is a combination of the O of the air with the C of the fuel at the bottom of the latter forming CO_2, but this, passing up through the red-hot fuel in the deep furnace, gathers up another portion of C and becomes CO at the top of the furnace. This CO is admitted to the chambers around the retort and there meets with another portion of O, becoming CO_2 and giving off the heat where it is required, around the retorts. The latter air supply is heated before it reaches the setting by having passed through a number of chambers sandwiched between the flues, carrying away the heated products of combustion, after they have completed their work among the retorts. By this means the temperature of such waste gases may be brought down to from 600° to 700° F., and the ingoing air has thus been raised to about 1000° F. In the complete combustion which takes place at the bottom of the fuel, each 1 lb. of C in this fuel requires 2·6 lb. O or 11·85 lb. air yielding 3·6 lb. CO_2 or 12·85 lb. CO_2 and N and 14,500 B.Th.U. As this 3·6 lb. CO_2 passes up through the hot coke it is decomposed to 2·3 lb. CO and 1·3 lb. O, and in doing so 10,100 B.Th.U are absorbed. Thus 4400 B.Th.U are evolved in the furnace proper; the 1·3 lb. O joins with another 1 lb. C and forms other 2·3 lb. CO, or in all 4·6 lb. CO. When the secondary heated air is again encountered, this 4·6 lb. CO is again converted to CO_2 by a further combination with 2·6 lb. O or 11·85 lb. air forming 7·2 lb. CO_2 and then evolving the 10,100 B.Th.U previously absorbed. For this definite chemical combination to take place it can be easily seen that only the exact quantity of air must be allowed to enter the furnace and setting, and careful chemical tests of the gases must be made to ensure that the right gases are being formed. In the producer on top of the fuel the analysis, if the coke were pure C, should show CO 34·7 per cent., N 65·3 per cent.; but now generally this is found to be as follows: CO 25 per cent., N 60 per cent., CO_2 8 per cent., H and CH_4.

The waste gases theoretically should be CO_2 20·8 per cent., N 79·2 per cent.; but here again a composition of CO 1 per cent., CO_2 16 to 18 per cent., N 83 to 81 per cent., is generally considered good working.

To calculate the quantity of air necessary for any coal or coke, it is sufficient if we know the percentage of carbon, hydrogen, and sulphur. The usual plan is to calculate first of all the weight of oxygen, from this the weight of air, and then the number of cubic feet required to burn 1 lb. As this will of course vary with the temperature and barometrical pressure, this has to be finally allowed for. If we take a coal containing 80 per cent. C, 6 per cent. H, 9 per cent. O, and 1·25 per cent. S, we should calculate the weight of air as follows:—

$$\begin{array}{lllr}
\begin{array}{c}C+O_2=CO_2\\12+32\end{array} & \text{then 80 lb. C require} & \dfrac{80\times 32}{12}= & 213{\cdot}3 \text{ lb. } O_2\\
\begin{array}{c}H_2+O=H_2O\\2+16\end{array} & \text{then 6 lb. H require} & 6\times 8= & 48{\cdot}0 \quad ,,\\
\begin{array}{c}S+O_2=SO_2\\32+32\end{array} & \text{then 1·25 lb. H} \quad ,, & & \underline{1{\cdot}25} \quad ,,\\
 & & & 262{\cdot}55 \quad ,,\\
 & & \text{deduct } O_2 \text{ in coal} & \underline{9{\cdot}00} \quad ,,\\
 & & \text{100 lb. coal require} & 253{\cdot}55 \quad ,,\\
 & & 1 \quad ,, \quad ,, \quad ,, & 2{\cdot}535 \quad ,,
\end{array}$$

$$1 \text{ lb. coal requires } \frac{2{\cdot}535\times 100}{23}=11{\cdot}02 \text{ lb. air.}$$

As 2 lb. O_2 occupy 22·4 cub. ft. @ 0° C. and 760 mm.

$$2{\cdot}5355 \text{ lb. } O_2 \text{ occupy } \frac{2{\cdot}5355\times 22{\cdot}4}{2}=28{\cdot}39$$

1 lb. coal then requires 28·39 cub. ft. O_2

$$\frac{28{\cdot}39\times 100}{21}=135{\cdot}2 \text{ cub. ft. air.}$$

1 lb. coal requires 135·2 cub. ft. air at 0° C. and 760 mm.; then if the requirement at say 20° C. and 750 mm. is wanted,

$$\frac{135{\cdot}2 \times 293 \times 760}{273 \times 750} = 147{\cdot}03 \text{ cub. ft. air,}$$

required at that temperature and barometrical pressure.

Mr. D. D. Barnum of Worcester, Mass., U.S.A., has shown what becomes of the energy in the coal after it is placed in the retort for carbonisation, from which a number of interesting points may be learnt. The figures are as follows:—

Heat Generated.	B.Th.U.
A. Heat from coke	215,623
B. Heat of formation	37,992
Total heat generated	253,615

Heat Distributed.	B.Th.U.	Per cent.
1. Carried up chimney as gases .	88,855	35·0
2. Carried up chimney as water vapour	31,943	12·6
3. Lost in ashes	...	...
4. Carried off by gas . . .	15,503	6·1
5. Carried off by tar . . .	4,070	1·6
6. Carried off by water vapour . .	3,759	1·5
7. Radiation and convection . .	20,931	8·3
8. Hot coke	33,708	13·3
9. Heat of formation of gases . .	3,267	1·3
10. Balance or heat utilised to decompose the coal . . .	51,579	20·3

The net heat of decomposition would be item 10 − item B + item 9, or $51{,}579 - 37{,}992 = 13{,}587$; $13{,}587 + 3267 = 16{,}854$ B.Th.U., or 6·6 per cent.

And this is the heat of decomposition furnished by the coke in the furnace, over and above the heat of formation furnished by the coal in the retort.

Professor T. Gray, D.Sc., has determined the comparative advantages of introducing steam into producers, and found that when the gas is to be used cold there is a greater thermal efficiency when steam is used; but on the other hand, with the gas made without steam, if used hot, so that, besides the heat of combustion, all the sensible heat in the gas is obtained, there is a small advantage (about 8 per cent. with flue gases at 600° C.) when no steam is used, because with the former gas, owing to the high specific heat of water vapour, there is a greater quantity of heat carried away by the products of combustion.

The lower the temperature of the flue gases the smaller the difference.

Steam, however, is required to keep the clinker fluid and make it more easily removed, but the preceding shows that as small a quantity as is necessary should be used.

Formerly the ends of the retorts were closed by iron plates and the joint made with clay. This of course had to be prepared fresh for each retort. To obviate this trouble, the self-sealing mouthpiece was invented, in which the surfaces are machined, the face of the mouthpiece being flat, and of the door rounded to a moderately sharp edge. The door is forced against the mouthpiece by means of a cam which also gives to it a sliding motion which serves to clear off tarry matters on the face of the mouthpiece. However, to ensure that such matters are removed and a tight joint secured, the scraping of the face of the mouthpiece with a stoker's shovel is an excellent safeguard.

The temperature of the retort is some 2010° F., and the gas passes up through the opening at top of the mouthpiece to the ascension pipe, thence over the arch pipe or bridge pipe and down into the hydraulic main. This hydraulic main is in reality a series of water-sealed valves through which gas from the retort finds its way to the other apparatus; but, as the dip pipe is carried below the surface of the liquid in the main, the pressure of gas forces the liquid up into the dip pipe and so seals it that the gas cannot escape when the door of the retort is opened. The great point in working the hydraulic main is to keep a liquor or water seal instead of a tar one, so as to give an easy passage for the gas as it bubbles through the water, the more viscous nature of the tar tending to stop the easy passage of the gas. In order to accomplish this, tar offtakes are provided and separate tar mains run to the well. In some works also a separate tar column is provided wherein the seal of the dip pipes can be accurately adjusted and the tar easily drawn off. The question of the removal of the tar from contact with the gas at an early stage, or allowing it to continue in contact with same through a lengthy condensing main, where the process is carried out at a slow speed, has been a matter of controversy for many years. If, however, the light tars can be recovered and utilised to wash the gas, after the heavy tars are removed, there is little doubt it would help considerably in the reduction of naphthalene deposits. Anti-dip pipes have been favoured by many, and there is no doubt of their advantages, as they allow the gas to pass direct to the main without having to bubble through the liquid. They have, however, all the one serious disadvantage in that they have to be closed by hand before the retort door is opened or else a serious loss of gas, and possible conflagration, may occur. The use of the retort-house governor, which has been so largely adopted of recent times, has enabled the trouble of the dip pipe to be largely overcome. Many attribute the increased make obtainable, when the retort-house governor is in use, to some wonderful inherent quality in the governor itself, whereas the only effect of the governor is that of an equaliser of the suction of the exhauster and its power of acting as a safety-valve, so that the seal of the dip pipes can be reduced to a minimum without risk of failure. It is this reduced seal which permits of the increased quantity of gas passing away from the retort, and the increased make is not the only advantage which these governors have: the greater security and freedom from anxiety which the manager has would alone warrant their adoption. Many makers of these governors propose the fixing of two governors of moderate size in preference to one large one, so that during the period of small makes the one can be closed off entirely and all the gas being made passed through the one only. Owing to the fact that there is a large quantity of tarry matter in the gas as it passes through these governors, it is impossible to make them so close-fitting as would be the case in a governor used for clean gas, and therefore they are not able to close down to such an extent, and the smaller size is on that account preferable. In designing such a piece of apparatus for Messrs. James Milne & Son, Ltd., some time back, I arranged the seat and coned valve in such a position that they could be easily removed and smaller ones fitted for the light makes, and in this way the one large governor served the double purpose. It is also useful where extensions are contemplated, as the full-sized governor can be erected at once and a reduced size of cone and seat used until the larger quantity is being made.

After the gas leaves the hydraulic main it contains some ethylene, some acetylene and vapours of volatile liquid hydrocarbons, some methane or marsh gas, some nitrogen, hydrogen, and CO. These three latter act as diluents for the richer gases, and beside these we have impurities which will be removed in the gas works, namely, tar and volatile oils, which will form about 33 per cent. of the gas as it leaves the retort, also 50 per cent. of water vapour, 3½ per cent. of ammonium salts (sulphates, sulphides, and chlorides), ammonium cyanide, and thiocyanate, 5 per cent. of CO_2, and 0·2 per cent. of sulphur in the form of sulphurett of carbon and organo-sulphur compounds. The temperature of the gas in the retort above the coal will have been about 1400° F.; this is reduced by the time it reaches the ascension pipe to about 400°, and falls further to about 130° in the hydraulic main. The travel through the various pipes leading to the condensers will reduce this temperature to about 100° F., and the condensers themselves will have to bring this temperature down to that of the surrounding atmosphere. The reduction in candle power, which has been general throughout the country, has enabled the use of much higher heats in the retort settings, and this has led to the manufacture of an increased quantity of naphthalene. This frequently causes stoppages in the condensers, the naphthalene being thrown down in flakes where the gas is cooled. To prevent the stoppages, Mr. Carpenter suggested the arrangement of the connections so that the travel of the gas through the condensers could be reversed, and in this way the naphthalene is swept away by means of the warm gas.

The mere cooling alone of the gas is not sufficient to remove all the tarry vesicles, so that friction grids or sieves are necessary to break up these bubbles. The impurities in the gas leaving the condensers are—

NH_3	0·9	per cent. vol.	or	250	grs. per	100 cub. ft.
H_2S	1·2	,,	,,	750	,,	,,
CO_2	1·5	,,	,,	1220	,,	,,
CS_2	0·028	,,	,,	49	,,	,,
Cyanogen	0·075	,,	,,	75	,,	,,
Other sulphur compounds				7	,,	,,

The gas as it comes from the retort has to pass through the various pieces of apparatus until it reaches the gasholder where it is to be stored, and will also have to pass through a number of pieces of apparatus which impede its easy flow and would cause a heavy back pressure in the retorts unless some means were adopted to counteract it. This is the exhauster, which, acting like a pump or fan, draws the gas through the condenser, hydraulic main, dip pipes, etc., from the retorts and afterwards serves to force it through the washers, scrubbers, purifiers, station meter, and finally to raise the weight of the gasholder.

The early exhausters were of the reciprocating order, in fact, the same as air pumps, having iron valves with leather faces. These were very simple to repair and seldom got out of order, but they caused oscillations in the suction, and the rotary type were then adopted, which keep the pull very much more even. There may be said to be two types of rotary exhausters at present in use—the single blade and the treble or quadruple blade exhausters.

In each case there is an inner drum to prevent the passing back of the gas, which has been drawn forward. It is claimed, and I think rightly, by the makers of the three and four bladed types that the speed of the exhauster for the passing of a given quantity of gas is much lower than with the single blade.

In the running of these exhausters it has been found that the best lubricant is the tar oil which is made during the distillation of the tar from the gas works. The main object to be obtained by an exhauster is to keep the suction upon the retorts as equal and as even as possible, any oscillation causing a variation in the quality of the gas and a deposit of hydrocarbon in the retort in the form of hard and almost pure carbon. The retort-house governor helps this steadiness, as has already been mentioned, but there are two forms of governors which are used in the exhauster house, one for the cutting down of the steam when the exhauster is pulling too much (this requires to be fitted with some form of the dash-pot so as to prevent any jumping of the governor shutting off the steam entirely); the other type of governor acts upon the valve on the bye-pass between the inlet and outlet of the exhauster and allows a certain quantity of gas to pass back and supply the exhauster with the amount needed, and such gas is, of course, pumped over and over again. Sometimes both of these governors are in use.

The importance of keeping the suction on the retorts even and at the desired amount has led to the designing of what is termed a pressure register, in which a paper-covered barrel is revolved by clockwork, upon which a pen indicates the amount of pressure or exhaust. In this way the attention, or want of it, on the part of the engineman is at once indicated. These registers are usually closed and locked so that they cannot be tampered with, and in France they are termed the "Mouchard" or "Spy," as they may be said to be constantly watching the engineman during the absence of the manager.

We have now to remove any remaining tarry vapours and the ammoniacal liquor, and to do this we have the tar extractors or washers, and after these it is customary to pass the gas first of all through a weak ammoniacal liquor because such ammoniacal liquor has an affinity for CO_2, H_2S, and any other sulphur compounds; which is not the case, to such an extent, with clean water. At the same time this process serves to strengthen the ammoniacal liquor so as to put it in condition to be used for making sulphate of ammonia, etc. Where there are two scrubbers, then the weak liquor is generally used in the first of these, while the second is supplied with clean water to take out the last traces of ammonia. In the form of scrubber known as the washer scrubber the water is made to enter at the opposite end from the gas, and thus as the gas leaves the apparatus it meets with the clean water last, so that all traces of ammonia may be removed. These vessels being divided into a number of compartments are usually arranged so that the liquor overflows from one to the other, and having run-off pipes at the bottom to clear out any tar if such should have been deposited. Generally one or two chambers at the end show no traces of ammonia. The composition of the gas as it leaves these scrubbers is as follows:—

H	48·55	per cent.	vols.
Methane (CH_4)	39·70	,,	,,
Illuminants	3·30	,,	,,
CO	2·50	,,	,,
CO_2	2·00	,,	,,
O	0·45	,,	,,
N	3·50	,,	,,

and we have still to remove all H_2S, amounting to, say, 650 grains per 100 cub. ft., CO_2 900 grains per 100 cub. ft., and CS_2 40 grains per 100 cub. ft. The washing of the gas by the weak liquor will remove a considerable quantity of the CO_2 and H_2S, probably some 20 per cent., as 100 vols. NH_3 combines with about 12½ vols. H_2S forming $(NH_4)S_2$ (sulphide of ammonia), and the same quantity combining with 50 vols. of CO_2 forming $(NH_4)_2CO_3$

(carbonate of ammonia). Many projects have been tried for the complete elimination of these impurities in closed vessels by bringing the liquor, after it has been used in the scrubbers, to nearly boiling-point, when the CO_2 and H_2S are expelled and the ammonia is ready to be used again. This boiling, however, only frees it of about four-fifths of the CO_2 and H_2S, the balance being combined with hydrochloride or sulphuric acids, and these cannot be freed. The Claus process aimed at forming sulphur in the free state direct from the gas, and this was done by exposing the liquor after it had absorbed the H_2S to CO_2, when the H_2S was set free and passed over heated oxide of iron with a quantity of air. Sulphur was liberated and deposited in baffling chambers in the free state. The liquor was then heated to 180° to 200° F., when the CO_2 was driven off, the latter being again used for decomposing ammonium sulphide in a fresh quantity of liquor.

Mr. H. L. Greville has put the matter of the requirements of NH_3 for the complete removal of the CO_2 and H_2S in a simple manner. Presuming that one ton of coal gives 36 gals. of 8-oz. liquor, this equals 6·3 lb. NH_3. At the outlet of the scrubbers we shall have some 11·6 lb. of CO_2 and 7·14 lb. of H_2S from the ton of coal. For the removal of the former we shall require 9·0 lb. NH_3, and for the latter 3·57 lb., or a total of 12·57 lb., or about double the ammonia that we now recover from the gas. If, however, we could pass steam, water gas, or hydrogen through the heated coke, the nitrogen, of which 50 per cent. remains in the coke at present, would be removed and would complete the NH_3 required to purify the gas in closed vessels. This is practically the foundation of the economy of the Mond gas process, which will be described later.

We now have to remove the remainder of the CO_2, H_2S, and CS_2, the bulk of which still remains in the gas. These are removed by what are termed the purifiers. Formerly these were boxes containing lime and water through which the gas was made to bubble. These were very effective, but the difficulty of disposing of the waste lime or "blue-billy," as it was called, was great, owing to the offensive smell of same. This system has therefore been obsolete for some thirty or forty years. To illustrate an article on Gas Manufacture which I wrote for a recent encyclopædia, the artist had drawn a gas works showing a number of these wet-lime purifiers; the second edition, however, has a correct drawing showing the more modern system of purification. With regard to the former impurity, this has no ill effect upon the atmosphere, when the gas is burned, and is in fact only the same product as is obtained from the complete combustion of the carbon with the oxygen of the air. The necessity for its removal, however, is caused by the fact that it has a deleterious effect upon the illuminating power of the gas, 1 per cent. of CO_2 reducing the illuminating power by 7 per cent. It is easily seen, therefore, that it is desirous that this impurity should be removed. The H_2S should of course be entirely eliminated. As regards the CS_2 and other sulphur compounds, up to within recent times, Parliament has insisted that in London and certain other big towns there should not be more of these than 17 grains in 100 cub. ft. of gas in summer, and not more than 22 grains in 100 cub. ft. of gas in winter, while the maximum amount of ammonia must not exceed 4 grains per 100 cub. ft. According to some experiments carried out for the late Sir George Livesey, the small amounts of sulphur compounds, which the gas would have in it if these impurities had not been removed, would have little or no effect upon the atmosphere of rooms in which the gas was burned, the lime in the plaster on the walls serving to absorb it; hence, largely owing to his efforts, the legal need for removing these compounds has been removed.

Formerly, the material in the purifiers was invariably placed in comparatively thin layers on several tiers of wooden grids and the gas passed up or down through these; consequently a good portion of the purifier was wasted, as the material could not be filled solid in them, or the weight of the portion above, pressing on that below, caused too much back pressure. Several forms of patent grid, such as the Jäger, Standard, and the Hurdle grids, have been invented of modern times. In the former the gas travels horizontally through what might be termed a species of louvres at the sides, while the triangular-shaped bars are superimposed. There is in no part of the purifier a great depth of material unsupported, consequently the density remains fairly uniform. With the Standard grids the bars are also of a somewhat similar pattern, but their tops, instead of being flat as in the Jäger, are shaped to form double springers, so that the material arches itself on these springers, from bar to bar; thus when the bottom is removed only the material beneath the arch falls away, leaving the complete arches from bar to bar. The material is here also packed practically solid, but the gas passes up through the material as in the ordinary plant.

Spencer's Hurdle Grid is fitted into the ordinary purifier at a slope slightly off the vertical, and the parts are placed so that every alternating tier of bars is centrally between the bar above and below. The material is thus broken up as it is thrown in, and falls from bar to bar, all the way down, on to the bottom tier of flat grids. Owing to the breaking up of the material, it is held light and loose and of practically equal density throughout the purifier. One advantage of these grids is the ease with which they can be adopted with ordinary purifiers.

Frederich Lux has, however, made experiments which show that the thickness of the purifying layer has no qualitative effect. This he tested with his purifying material, which is a hydrated oxide of iron with a certain amount of free alkali (soda).

This, if equally true of ordinary oxide, which may be presumed, would show that a depth of oxide in the purifier would be of advantage only as regards the time between the opening of the purifier, and that the rate of flow of the gas could not be increased. He concludes, from his experiments, that 7 sq. ft. per 10,000 cub. ft. maximum make per day is required ; this gives a maximum rate of flow of 0·0164 ft. per second.

It might perhaps be best to describe the arrangements necessary for the complete purification of the gas from the three impurities, CO_2, H_2S, and CS_2, as this will explain several of the reactions taking place in the more simple arrangements for purification adopted in smaller works. For this purpose eight purifiers are required, worked in pairs, so as to permit of renewal of the material used when necessary. The first pair of purifiers are usually filled with hydrated lime ; that has an affinity for both CO_2 and HS_2, combining simultaneously as per the following equations :—

$$CaH_2O_2 + 2H_2S = CaS, H_2S + 2H_2O,$$

or

$$CaH_2O_2 + H_2S = CaS + 2H_2O,$$

and

$$CaO + CO_2 = CaCO_3.$$

As the process of purification continues, the lime having a greater affinity for the CO_2 than for the H_2S, the latter is thrown off and the CO_2 taken up in its place as follows :—

$$CaS + CO_2 + H_2O = CaCO_3 + H_2S.$$

If, however, some air is admitted, then some of the H_2S will be converted into free sulphur and remain in the purifier. As regards the quantity of these two impurities which may be absorbed by lime, it may be pointed out that 1 lb. of pure hydrate of lime or 0·757 lb. of pure lime will absorb 0·59 lb. CO_2 or 0·46 lb. H_2S, and, as will be described later, 1·03 lb. CS_2. Thus, after the first pair of purifiers are passed, the gas is completely freed from CO_2 and the next pair of purifiers are used for the purpose of removing the H_2S, and these are generally filled with hydrated oxide of iron, which when prepared ready mixed for the purifier will contain some 50 per cent. hydrated ferric oxide, 1 per cent. of silica, 20 per cent. organic matter, and 29 per cent. moisture. The S unites with the iron in the oxide to form iron sulphide, whilst the H unites with the O to form water as follows:—

$$Fe_2O_3H_2O + 3H_2S = 2FeS + S + 4H_2O.$$

Whereas the lime, when it is used for the removal of H_2S, is used up, and only a waste product, the oxide can be revivified. On the first time it is put into the purifiers it will absorb the H_2S until there is some 11 per cent. of sulphur in the oxide, and the quantity removed each time the material is used will gradually diminish to 8 per cent. until some 50 or 60 per cent. of sulphur is contained in the mixture. When the iron sulphide is exposed to the atmosphere it reabsorbs O from the air, depositing sulphur in the free state and restoring the iron to the oxide condition as follows:—

$$2FeS + H_2O + 3O = Fe_2O_3 + H_2O + S_2.$$

During the process of revivification the oxide becomes heated. One ton of good oxide should eliminate the H_2S from some 3,000,000 cub. ft. of gas.

We now come to the work to be done by the third pair of purifiers, namely, removal of the CS_2. Here we have another instance of the use of a fouled material where a clean one would have no effect, as lime when clean has no effect upon CS_2, but hydrate of lime, which has already absorbed H_2S and become a sulphide of lime, will then take up the CS_2 and throw off an equivalent of the H_2S, which it had already taken up. To obtain this sulphide of lime the second pair of purifiers are bye-passed for a time, so that the gas containing the H_2S, but free from CO_2, passes direct to the third pair of purifiers, where such H_2S is absorbed. This is of course done in the one purifier at a time, so that there is always one of the pair of purifiers containing lime sulphide, and the CS_2 can be arrested. Thus, at the end of the third pair of purifiers the gas will contain only some small quantity of H_2S as an impurity which has been thrown off as the CS_2 was absorbed, and this is removed by the last pair of purifiers, which are commonly termed "catch or check" purifiers. As these have only to remove the H_2S, they are generally filled with oxide of iron or "Weldon mud," which is an oxide of manganese. Where the lime has been used solely for the removal of the CO_2 it can be returned to the original condition by burning it again, as it is in a practically similar condition to the chalk or limestone from which the lime was originally made. Mr. Hislop, the Engineer of the Paisley Gas Works, has invented a simple system of reburning, which has saved a considerable expense, in the purchase of new lime, where it has been in use.

Composition of the gas leaving the purifiers:—

Hydrogen (H)	53 per cent.
Hydrocarbons (C_nH_n)	37 ,,
Carbon monoxide (CO)	5 ,,
Carbon dioxide (CO_2)	0·7 ,,
Nitrogen (N)	4·0 ,,
Oxygen (O)	0·3 ,,

The measurement of gas in a gas works is always done upon the make and not upon the sale, as the manufacture is continually going on throughout the twenty-four hours, whereas the bulk of the quantity supplied passes out within two or three hours of the early evening. The meter can thus be of a much smaller size than would be necessary if the supply were to be measured.

A type of meter known as the Rotary has been designed of recent years, which has reduced the size of the apparatus required for large quantities. The gas is made to pass up through a number of small holes and to play upon a fan which it causes to revolve, the number of such revolutions being shown by an index above the casing. If only a small quantity is passing it will fail to lift the valve provided and will then pass through pipes and play upon the ends of the fans, thus revolving them. These meters are not strictly accurate at all speeds, but the variation is probably not more than about 5 per cent.

at any time, and the meters are very useful where extreme accuracy is not needed.

To ensure that a sufficient quantity of gas is passed into the mains in accordance with the requirements of the consumers, a form of governor must be provided, as of course it is advisable to keep the pressure low to prevent as much leakage as possible, as it is almost impossible to ensure that all gas mains shall remain tight, owing to heavy traffic and other causes of subsidence to the roads. The governor has to maintain automatically at the outlet of the gas works a constant pressure upon the outgoing gas, whatever the variations of pressure may be in the inside of the works or outside resulting from the lighting or extinction of burners upon the system of mains. These variations of pressure actuate the movable cone or valve, and cause the apparatus to deliver the gas proportionally to the needs of consumption. The weight of the bell of the governor is counterbalanced, either by weights pendant from a chain passing over a wheel, or by means of floats in the bottom of the bell immersed in water, or by a combination of the two methods. The bell, therefore, being in equilibrium, the pressure of the gas has a natural tendency to cause the bell to rise, and weights have therefore to be either put upon the bell or taken off the counterbalance weights, to again bring the bell into equilibrium; the amount of weight regulating the pressure of the gas necessary to effect this, and thus regulating the pressure at which the gas shall pass away into the town mains. But to return to the description of the ordinary gas governor. The gas, after it has passed the cone, is at liberty to press against the top of the bell, and it will then raise it and with it the cone or valve which is fixed to it by a chain or rod, at the same time reducing the space between the cone valve and its seat in direct proportion with the rise and fall of the bell. It is on this account that the cone is made of a parabolic curve instead of a straight cone, the parabolic shape being the result of the calculation of the necessary size of the cone at different points of its travel, to ensure an even and exact reduction of the area of the gas passage way between the top and the bottom of the travel of the cone.

When the gas in the mains is being consumed rapidly, the pressure tends to fall; then the counterbalancing of the bell by the pressure of gas is reduced, with a consequent fall of the bell and an opening of the passage way for the gas, which permits a greater volume to pass until the balance of pressure is once more restored; and this goes on continuously, the cone valve opening and closing as required. The pressure of the gas at the outlet to the town mains is decided upon by the engineer, and weights are either put on or taken off as the pressure is required to be greater or less. These weights should not be put on or removed too suddenly, or the rapid change in pressure may cause the whole of the lights in a town to be extinguished. The first governors were not compensated, so that any alteration of inlet pressure caused a variation of the outlet pressure owing to the pressure acting on the cone. This was overcome in several ways, first by separating a portion of the bell equal in area to the base of the cone and bringing the inlet pressure to this, while the outlet pressure acted upon the larger area of the remainder of the bell. In this way any alteration in the pressure upon the cone was counterbalanced by an equal pressure in the opposite direction upon the bell, and the outlet pressure thus kept constant. Another plan adopted is to use two cones, so that the incoming gas presses against the top of one and bottom of the other and is thus counterbalanced.

Sometimes in place of a cone a number of slots are used which are opened to a greater or less extent as required. Further improvements have included the placing of the bell and its tank away from the top of this cone case. The Foulis Governor is of the 2-cone type, and is worked by a bell placed at any convenient distance from the governor proper, and weights, put upon the bell, compress the air in same, and this is conveyed through a pipe to the under side of the cone-bell; the outlet pressure of the gas has then to counterbalance this compression. This governor is also provided with a dash-pot to prevent the pressure being altered too rapidly. This arrangement frequently saves considerable piping, as the governors can be put in a pit in the line of main which need not be diverted to a governor house, as the regulating bell can be fixed in a cast-iron pillar-box on the street, as is done in several places in this city. Where high pressures are required, mercury can be used in this governor, when the cone-bell must be of black iron and preferably welded at the joints.

The enrichment of gas is becoming less necessary every day, as the heating and not the lighting power of gas is required, which is the case where incandescent burners are being introduced. Benzol, however, is being used, and, where only one or two candles' enrichment is required, serves the purpose admirably. If, however, more than this amount is desired, then there is the possibility that the gas so enriched will not carry the extra vapour, if subjected to cold, and some of it may be deposited in the mains.

The usual plan is to pass a proportion of the whole gas through a piece of apparatus, where the benzol is subjected to some heat, and consequently fully vaporised, and then to mix this portion of the gas with the bulk.

Ordinary steam heat of 212° F. is quite sufficient, as benzol boils at 177° F., so that exhaust steam may be used. The amount of enrichment is variously stated by investigators at 4500 to 15,000 cub. ft. enriched 1 candle per gallon of benzol. Benzol as an enricher of coal-gas is no doubt good from an illuminating point of view, as it is said that its vapour is worth ten times the value, as an illuminant, of coal-gas. But when we come to its calorific value we find it is distinctly deficient. One gallon of benzol may be said to be equal to the giving of 160,000 B.Th.U., and if this gallon can be used to enrich, say, about the mean of the results mentioned or 8000 cub. ft., and raise it one candle, then this candle will be obtained for the addition of only 20 B.Th.U. per cubic foot, whereas the average calorific value per candle of coal-gas is 40 B.Th.U. per candle.

CHAPTER IV

Distribution—Lighting—Meters: wet, dry, prepayment—Burners, old and new—Oxygen and air required for combustion—Light *v.* heat — Flame temperatures — Mantle-making — Reflection—Lighters—Pneumatic-electric-spongy platinum—High-pressure lighting.

THE gas meter has probably been the butt of the comic papers since it was first invented by Clegg, in 1815, and this is largely because its functions are only imperfectly understood. I shall show by models, sections, etc., how the meters work, and then perhaps I shall have convinced you, that as far as is humanly possible, the gas meter, as now made, is as nearly a perfect instrument as can be expected. Before, however, we examine into the construction, it might be worth while considering the merits of the two kinds of meter—wet and dry. The former is the older, and is certainly the more accurate, when the level of the water is kept at the proper height. All test meters and station meters are made of this type, and this alone would indicate their greater correctness. I have just said that the water must be kept at the proper level, and herein lies one of the principal troubles with the wet meter, as if this is not attended to it may get so low that the supply of gas is completely shut off; every meter being provided with a species of ball-cock, which shuts a valve on the inlet of the meter when the water gets so low that gas would pass unregistered at a lower level of water. This shutting-off point, it has been decided by the Legislature, is to be when the meter shall be registering 3 per cent. slow—that is to say, when 103 ft. are passing through the meter, but only 100 being registered. In the same way the limit as regards the filling of the meter, or the high level, is fixed at 2 per cent. fast, or when 98 ft. are passing and being registered as 100. The principal objection to the wet meter, apart from this necessity of regular watering, is that the water evaporated by the passing gas is deposited in the pipes whenever they are at a lower temperature than the gas at the meter; and should these pipes have been badly laid, any sag in them will become filled with water and cause a blinking, if it does not completely extinguish the light. The plumber of course lays the blame upon the wet meter and not upon his faulty workmanship, hence the bad name this meter has obtained. Frost also may attack the water and prevent the movement of the drum and the consequent passage of the gas.

The meter drum is a cylindrical vessel divided into three or four compartments, each having its own entrance and exit, so fashioned that, as it revolves, the inlet of each compartment is carried below the water before the outlet comes above it, so that they are never both open together. Thus the ingoing gas is always entering the compartment before the one which is being emptied, and, by its pressure against the division, causing the drum to revolve and the gas to exit from it as the various compartments are carried under the water, in which it is immersed for about two-thirds of its depth. It is clear that if the water is at a high level in the drum there will be little or no room in it for the gas.

The principle of the dry meter is that of a pair of circular bellows, into and from which gas passes alternately, which bellows are capable of being regulated to open only to such a degree at each filling that they may thus contain a certain definite quantity. It must be, however, remembered that not only is the interior of the bellows used for measuring the gas, but also the two cases within which these bellows work; as, when gas is passing to the inside of the bellows, it is forcing out an equal quantity from the case, and *vice versa*. The gas is admitted into the four compartments by means of D slide valves, very similar to those used on steam-engines, but made of exceedingly hard white metal. These valves are placed at 90° to each other, so that the two connecting rods can be fitted to the one crank, while the opening and closing of the valves will take place in proper rotation. The movement of the bellows is connected to an upper chamber by what are termed "flags" and "flag wires" to the upper end of which are attached hinged arms which rotate the crank, actuating the valves. Attached to this crank is a worm which drives the index to indicate the number of times the bellows are filled and emptied. These hinged arms are attached to a pin on what is termed a tangent, which is capable of having its radius varied as required. The collapsing portion of the bellows is made with Persian sheep-skins, which are tied on to the rims with wire and thoroughly painted with a mixture of oils.

The index of either kind of meter is practically alike and usually consists of three dials. The reading of these indices is not always understood. It should be first of all noted that the figures on each of these dials do not all read alike: the first and third dials are usually numbered clockwise, and the middle dial the reverse way. The figures on the first or right-hand dial represent hundreds of feet; the next, thousands of feet; and the third, tens of thousands. In reading such an index, when a pointer is between two figures, the figure next below it in value should be taken, as we should do if the hands of a clock pointed to 5.55, the hour hand then being practically pointing at the 6. We know, however, that it has not reached the 6; and in the same way, if the hand of the dial next to the right, or the one we are reading, is, say, at 9, we know then that it has nearly completed the circle, and consequently we may expect the pointer of the other circle to be nearly at a figure. It must be remembered that the figures shown on the index always require two nothings (*i.e.*, 00) added to them to show the exact reading. In the case of the dry meter, there is a small circle on the index usually showing two feet in the circumference, and the wet meter has a leaden drum with figures on its circumference: both these are for the purpose of testing the meters, but they can be used with advantage to find out leaks or to indicate the consumption of a burner or stove.

The testing of the gas for illuminating power has been a vexed question between the authorities and the suppliers of gas for many years. The idea of these tests has always been that the gas should be tested when burned in the best available burner which a consumer may obtain, but now that it is not the light of the white-hot carbon in the gas which is generally utilised, but the heating power which it can deliver to a mantle of the rare earths, the burner which has been chosen by Parliament does not conform to the standard formerly laid down. It is, however, the best available for testing the gas *per se* as a lighting agent, and the No. 2 Metropolitan argand, as it is called, is capable of giving some two candles more light than the No. 1 London argand formerly used. This is attained by the use of a regulator of the air under the burner, which permits of its adjustment to the exact quantity required for the quality of the gas being tested. A rich gas cannot, however, be tested in this burner at the usual rate prescribed, namely, 5 cub. ft. per hour, but a smaller quantity has to be used, and a rule-of-three sum converts the result to the standard rate.

The Letheby Bunsen bar photometer has been recently largely superseded by the Referees Table Photometer, in which the beams of light from the standard and the gas being tested are brought side by side upon a piece of tissue-paper instead of on each side of a greased disc. This with the use of the Harcourt 10-candle pentane standard, which has now been tested by various authorities all over the world and has been allowed to be within 0·5 per cent. of accuracy, which is much above the limit of the accuracy of the older candles, has considerably reduced the time required to carry out a test from that required with the older type of photometer. Seeing that probably 80 per cent. of the gas now supplied is used for the heating power which it is capable of giving off, the test which is most necessary is that for its calorific power. There are several excellent calorimeters, notably the Junker, the Simmance-Abady, and the Boys, each named after the inventors. These show, by the heat absorbed by a quantity of water running through them, the amount of heat given off by the gas. At present this test has not been prescribed in any Act regarding the supply of gas, but that it must come before long is evident, when it is considered that a gas of any given c.p. may vary as much as 20 per cent. in heating value. The composition of the gas supplied varies so greatly even at the same c.p. that no exact figures can be given for conversion of c.p. into B.Th.U.; and further, the question of the admixture of carburetted water-gas has to be taken into consideration, as this again alters the composition. If we know the exact composition of the gas, we can calculate the heating value as follows. If we take a gas containing say H 50 per cent., CH_4 36 per cent., CO 5 per cent., benzene 0·5 per cent., ethylene 4·5 per cent., and N 4 per cent., then by multiplying the percentage of hydrogen by 326·2, the percentage of CH_4 by 1024, the percentage of CO by 323·5, the percentage of benzene by 3718, and of ethylene by 1603, we obtain the heating value of 100 parts, so that the total of these added together and divided by 100 gives us the required B.ThU.'s. in one cubic foot of the gas. It may be mentioned that the nitrogen, having no heat value, is ignored. Working out these figures, we find a total of 63,864 heat units, which divided by 100 gives us 638·64 B.Th.U.'s per cubic foot of the gas.

To understand any kind of lighting by gas, we must first familiarise ourselves with the theory of the cause of luminosity. Clean gas, I may repeat, consists of—

Hydrogen (H)	53 per cent.
Hydrocarbons (C_nH_n)	37 „
Carbon monoxide (CO)	5 „
Carbon dioxide (CO_2)	0·7 „
Nitrogen (N)	4·0 „
Oxygen (O)	0·3 „

or, say, ½ hydrogen, ⅓ marsh gas, and $\frac{1}{20}$th carbon monoxide, none of which give light of themselves; it is about $\frac{1}{20}$th part of the whole, which is heated by the other gases, and which forms the light-giving part of the gas. These hydrocarbons or combinations of carbon (C) and hydrogen (H) combine with the oxygen (O) of the air to form water (H_2O) and carbon (C); thus, $CH_2 + O = H_2O + C$. The heat of this combination makes the carbon become white-hot, and this carbon passing to the outside of the flame combines with two molecules of oxygen (from the air) to form carbon dioxide; so that the products are H_2O and $N + CO_2$, which latter compound is the result of all combustion. The water (H_2O) is condensed on the first cold object it encounters, generally the ceiling, and there holds any dust or dirt which is moving about in the atmosphere. This dust can be noticed on a hot day with the sun streaming into a room through a slit. This, and not soot, as is generally supposed, is the cause of dirty ceilings.

The question of the cause of the great radiation of light from the rare earths has troubled the minds of many scientific men, some of whom attribute it to a power of selective radiation, while Lord Rayleigh points out, like a practical man, that the light emitted is always greatest when the flame is hottest, and therefore holds that temperature is the governing consideration. The temperature to which an incandescent mantle is subjected is a very high one (some 4000° F.), above the melting-point of platinum, and the shape of the net-like mantle seems to keep the flame in such form as brings the hottest part of it where the mantle is.

To show the advantage of keeping a mantle clean and free from dust, it may be mentioned that a mantle can be rendered non-illuminating if dipped in ink, and thus coated with an iron oxide. This accounts for the fact that a mantle which has been upon a burner unused during the summer, and accumulating dust, fails to give a satisfactory light when tried as the days get shorter.

REFLECTION POWER OF COLOURED SURFACES

White paper or new white-washed ceiling	80	per cent.
Orange wall-paper (clean)	55	„
Yellow „ („)	40	„
„ „ (dirty or dark)	20	„
Green „	10 to 46	„
Blue „	6 to 30	„
Pale red „	16	„
Brown „	15	„
Deep chocolate	4	„
Dead black	1	„
Tracing cloth	30	„
Planed deal (clean)	45	„
„ (dirty)	20	„
Macadam road	about 8	„

I suppose no amount of statistics as to the loss of light in a room, due to the choice of a dark-coloured wall or ceiling paper, will induce the good lady of the house to adopt anything else but the particular colour and shade which she considers suits the furniture or general appearance of the room. Nevertheless, I give a table showing how much loss of reflected light is obtained by the different coloured wall-papers generally in use. This question of the reflective power of ceilings and walls is a most important one, if a nicely diffused and equal light is desired, whether the room be lighted by the central gasalier or by brackets around the walls If the former place be adopted, then to obtain the best light upon their books, a family should sit in a circle, with their backs to each other, with the light in the centre. This would not be a very sociable position. The only excuse for the centre light is when it is over a table, and occupants of the room are likely to be seated around it facing inwards, either dining or working upon it.

A point with regard to angles in connection with lights is the angle which the surface of the object to be lighted makes with the ray of light. This varies as the cosine of the angle, which the luminous rays make with the normal of the illuminated surface. This becomes of considerable importance when we consider the lighting of a horizontal surface, such as a street, but is also important when we are reading, as, to get the best light upon our book, it should always be held at right angles to the ray of light.

It is important to know what is the minimum amount of light required for various purposes, and the following table may be useful:—

Street lighting, minimum				$\frac{1}{20}$	candle foot.
Workshop lighting, general, minimum				$\frac{1}{8}$	„
„	„	benches	„	3	„
Domestic	„	general	„	1	„
„	„	table	„	2	„
Church	„	pews	„	2	„

However, there is one fundamental and simple calculation from which we can judge others. This is, that for reading, the minimum amount of light required is that given by one candle at one foot from the object. We all know that it is possible to read with this amount of light, and have probably all done so at one time or another, perhaps when carrying out that objectionable practice of reading in bed. While I do not advise the use of such small units as the single candle, I am a great believer in the use of a number of sources of light rather than one large central burner. However, it must be borne in mind, when arranging the lighting of any building, that the sight will be dazzled if there are too many of these small points in the line of vision. Remembering the law that light diminishes as the square of the distance, we shall see that we can get as much light from an 8-candle power lamp at 2·83 ft. from same, as we can at 5 ft. from a burner of 25-candle power.

The old rule for finding the number of burners required to light a room was the floor area in square feet divided by 50. This was at the time when flat-flame burners were in use, so the rule will require altering, and a devisor of say 100 will be more near the mark as, although the incandescent burner will give perhaps five or six times the light of the flat flame, we have become accustomed, and now desire, a much higher illuminating power than we were satisfied with formerly. Returning to the old rule of the flat-flame burners in a room 10 ft. × 10 ft., this only gives say 20-candle power, and the full light to be obtained upon a book at 3 ft. from the floor and 2 ft. from the wall, including all reflections from a white wall, only equals ·86-candle foot. This will show the importance of the light of coloured wall-papers.

For setting out the lighting of any building, diagrams should be made showing the radius of the various candle powers from each centre, and where reflections occur these also should be shown.

While we were referring to the question of reflections, it might have been well to call attention to the reflecting power of the usual opal reflecting globes with clear glass below, used with incandescent burners. The sides of these are usually at about 45° to each other or each 22½° from the vertical instead of the correct angle, which is about 90° or 45° each from the vertical. In the former case the light is spread outwards to some slight extent, but little or no light is reflected downwards, where it is required; whereas with the latter the downward light is considerably increased, while the light spread is little if anything reduced.

The effect of pressures on a flat-flame burner are as follows:—

Effect of Different Pressures on a No. 4 Union Jet Burner

Pressure in Inches.	Consumption in Cubic Feet.	Unit Efficiency in Candles.
0·5	3·9	3·0
1·0	5·6	2·4
1·5	7·0	1·9
2·0	8·45	1·5
2·5	9·6	1·35
3·0	10·5	1·11

Samples of the various burners in the order of their invention were exhibited. The three burners, the rat-tail, the union jet, and the kern burner, showed the amount of light obtainable from the same amount of gas—each being governed to consume 3 cub. ft. per hour.

The bunsen burner was invented in 1852 at Heidelberg. In 1883 Clamond made a mantle or basket of magnesia rods. This gave some 4 candles per 1 foot, but was not commercially successful.

The discovery of Welsbach was, as usual, the result of an accident. Welsbach was making researches in connection with the rare earths, curiously enough in the same laboratories as those in which the bunsen burner had been first tried. A beaker of rare earths in solution boiled over on to an asbestos card with rough edges, when the portion where the asbestos fibres were finely divided gave off an intense light when heated by the bunsen flame underneath. Welsbach at once tried cotton fabrics soaked in nitrates of the rare earths, and then tried mixtures, taking out a patent in 1885, which was not a success. He continued experimenting, and in 1886 patented the use of thorium, which, as then made, contained small traces of foreign oxides. He concluded at first that thorium was the oxide which gave the best results, but when really freed from the foreign matter thorium only gives half a candle per cubic foot of gas. One per cent. cerium to 99 per cent. thorium gives best results, but 2 per cent. cerium reduces the candle-power until with 10 per cent. cerium the mantle only gives the same light as if thorium only was used. The reason of this is that the cerium is a splendid heat radiator, and consequently a large quantity of it takes the heat from the flame and radiates it into the air instead of utilising it to heat the mantle. The heat necessary to obtain the full value of light from the cerium is at least 1500° C. There is also a catalytic action which gives a higher temperature than that of the flame; and besides these two advantages, there is the third, that the light is from the yellow and green parts of the spectrum. All these combine to give the marvellous amount of light obtained with the incandescent burner.

The mantle is made as follows:—A "cone" or spool of No. 40 white cotton or ramie thread is knitted into a "stocking" or hose about two inches in diameter. This stocking is thoroughly washed and dried. Then it is saturated with a solution of nitrate of thorium and 1 per cent. of nitrate of cerium. The thorium is manufactured from a sand called monazite, which is found in Brazil and in the State of Carolina, and is rather expensive, being sold at 20s. per pound. One pound of nitrate of thorium yields from 300 to 340 mantles, depending on the quantity distilled. After the cone has been washed and dried, it is either cut to proper size and impregnated with the thorium solution, or is first impregnated and then cut to the required lengths. The impregnated stockings, after being cut and dried, are sewed at one end with asbestos thread, so as to form a head provided with a loop, which serves to hold the mantle in process of manufacturing and when in use on the burner. Then the impregnated stocking is hung on a wire by an asbestos loop, and heated in a gas flame of the bunsen type. This is done in order to burn out the thread. The next process is called the shaping. The mantle now consists only of ashes of thorium (oxide of thorium), and is carefully held over a high-pressure bunsen flame, and gradually given the right shape, at the same time being hardened. As soon as the mantle is shaped and hardened it is practically completed, but in order to protect it from breakage it is "dipped" in a stiffening solution. There are many forms of "dip," but the one most used is made of soluble cotton (gun-cotton) dissolved in good alcohol and acetone. To this mixture castor oil and shellac are added. Before the mantle can be used on a burner this "dip" or coating must be burned off.

Instead of cotton, as just described, a fibre called "ramie" is now generally used.

Ramie is a grass that grows about 5 ft. high; its Latin name is *Boehmeria nivera*, but put in plain English it means nettle. Ramie is a gigantic nettle, and it grows in India, where it is used for making cloth. The bark or skin of this nettle is full of a long silky fibre, which has been called the "noblest fibre nature has given." Its length runs up to quite 9 in., and it is this which makes it so valuable for the production of incandescent mantles. Owing to the length of the fibre, a yarn is able to be made which, when converted into an incandescent mantle, does not shrink, and therefore does not lose its light like the cotton mantles, which, when they are first put on, are in the outside zone of the flame and give an excellent light, but in the course of a few hours' burning have shrunk so much that they are in the colder interior part of the flame, and are now giving only about half the light they started with.

Another type of mantle is the "Collodion," which is made of fibres of collodion squeezed through a fine hole in a plate and then woven. It is the structure of the fibre which is mainly responsible for the extra life of the ramie and collodion mantles. In the cotton mantles the thread is a plaited rope of myriads of minute fibres, while the ramie thread is not so tightly plaited nor does it contain so many or such fine fibres. The collodion again is almost straight in its fibre, with hardly any twist and of much fewer fibres, although a finer fibre is said to still further increase the life.

The wick of a candle shows us why the life of a mantle should be increased when the twist in plaiting is reduced. It will be remembered that the old tallow candle, which required frequent snuffing, had its wick very little if at all twisted; while the modern wick is very much plaited, and this causes the wick to bend at the point when burned, and so is brought out of the zone of flame and into the oxygen of the air, so that its carbon can combine with it, and it is consumed during the formation of CO_2. The old wick, being always straight and inside the flame, could not get the necessary oxygen for its combustion, and therefore required snuffing. If we apply this lesson to the mantle, we shall see that the less twist in plaiting there is, the more likely is the mantle to retain its original shape when burnt, and so the great strain upon the threads is removed, and with the absence of this strain the likelihood of fracture is much reduced.

As regards the light which will be emitted from a Welsbach mantle by any gas, we require to know that the gas is being consumed in the manner which will ensure the hottest possible flame, and in this lies the foundation of the success of the burner design. If we have a bunsen flame with the inner *violet* cone, probably the hottest part of it will only be at 2800° F., and the light given by the mantle will equal 20 c.p. per foot. If, however, the green inner cone is obtained, by a better admixture of air and gas, then the temperature, or the hottest part of the smaller flame, will be about 3000° F., and the light obtainable 30 c.p. per foot of gas. If the gas and air are heated before nearing the point of issue from the burner, which may be done by utilising the heat of the burner itself, the temperature of the flame will be raised to such an extent as to show a 50 per cent. increase in the light of the mantle.

The air required for combustion is a definite quantity according to the constituents of the gas, and is calculable from its analysis. Rich gases require more air and less gas. It might be interesting to examine the quantity of air required to ensure complete combustion with a sample of gas containing say H 53 per cent., CH_4 37 per cent., CO 5 per cent., CO_2 10 per cent., N 4 per cent.

Then for the H we shall require half the volume of O, or 53 cub. ft. H require 26·5 cub. ft. O.

For the CH_4 we shall require twice the volume of O, or 37 cub. ft. CH_4 require 74 cub. ft. O.

For the CO we shall require half the volume of O, or 5 cub. ft. CO require 2·5 cub. ft. O.

The CO_2 and N, being non-combustible, do not require O.

Thus 100 cub. ft. of this gas require 103·0 cub. ft. O.

Thus 1 cub. ft. of this gas requires 1·03 cub. ft. O, and, as O in the air is 21 per cent. by volume, we have $\frac{1·03 \times 100}{21}$, say 4·9 cub. ft. air required.

Of this quantity, if about 40 per cent. is admitted into the bunsen holes of the burner, and 60 per cent. taken from the air around the flame, we have the violet inner cone, large flame, and low comparative heat; if, however, 60 per cent. can be drawn into the burner with the gas, then only 40 per cent. will be required around the flame, and we shall have the green inner cone which indicates the greatest heat, at ordinary pressures, with a smaller flame, but more intense.

The heat of gas is the same, no matter how it is burnt, provided perfect combustion is obtained, and this with a flat flame, bunsen flame (with either violet or green cone), or high-pressure or blow-pipe flame. The temperature is the same throughout for the same quality of gas, but the size, and consequently the intensity, varies. The smaller the flame for a given consumption the greater the heat. The proportions of a bunsen burner are perhaps best expressed in terms of the diameter of its tube. If this be taken as 1, then the gas outlet for 15 to 16 candle gas should be less than $\frac{1}{8}$ in. The mixing tube if horizontal should be 5 and if vertical 8 in length, and the outlet of the burner under 1; and if gauze is used in the outlet, then air space between the meshes should equal 1. The position of the gas jet at low pressure should be at the centre of air hole. Another way of stating the proportions is that the mixing tube should be 75 times the area of the jet, which will give a gas velocity of 882 cub. ft., which escapes from the orifice at 35 cub. ft. velocity and draws in 3 vols. of air.

The inverted bunsen is no doubt very unnatural, but as it is the means of providing light where it is required—namely, in a downward direction—the public have the right to demand such burners. Still, it must not be lost sight of that heat ascends; gas, being lighter than air, ascends; flames burn upward; being warmer and therefore lighter than air, the gas issuing from the nipple has to induce a current of air, which is being warmed and made lighter, to pass in the contrary direction to that arranged for by nature's laws. This last is one of the principal troubles with the inverted burner, especially where gases of a very rich nature are in use, as it is the flame with the green cone we require, and for this we need as much air taken in by the gas as possible (as before mentioned, 60 per cent.). If the gas is rich a greater quantity of air is required for this perfect combustion, and this has to be effected by the issuing of a smaller quantity of gas; and unless the pressure of such gas is high, this will not take place, and a smoky flame will result. It might be mentioned that it is quite possible to mix such a quantity of air with the gas as will supply not only the 60 per cent. required in the burner but also the 40 per cent. usually taken from the air around the flame. This is done in the so-called safety petrol gas systems now being largely introduced into country houses, and which will be described shortly in the next lecture.

I have made a list of some of the points requiring improvement in most inverted gas burners. These are carbonisation, and consequent blackening of mantles and choking of the passages for the egress of consumed products, and falling of hot carbon particles; burning back when first lighted, roaring, breaking of mantles through explosion when lighting; low pressure, causing flickering and imperfect mixture of gas and air. Unless there is sufficient pressure of gas (this should be not less than 2 in.) there cannot be enough to cause the injection of the proper quantity of air and the projection of the mixture in a downward direction. Unless this mixture is rightly proportioned and mixed we cannot have the inner cone of that bright green colour which indicates the hottest flame. The introduction of the regulating nipple, which allows the full pressure of the gas to reach the issuing point, is perhaps the most important advance in the inverted burner of recent times, as this ensures the full power of the gas being exerted for the injection of the air even when only a small quantity of the gas is being used. It also allows of the use of gases of different heating powers in the same burner, and when to this is added a means of regulating the air, a burner is provided which is capable of giving the maximum effect from the gas consumed. Considerable heat is thrown off from an inverted burner, and some recent patents have for their object the utilisation of such heat to increase the luminosity of the mantle: such a one is the "Pharos" burner, invented by two gentlemen in this town, in which the heated products of combustion pass up around the air intakes and the mixing tube of the burner, so that the issuing mixture has reached a considerable temperature before it is lighted. The heat of the issuing gases is nearly 500° F., which is obtained from the heat which would otherwise be wasted. Another point about this lamp is that the air taken in to supply the necessary quantity of oxygen to the flame is not contaminated with the consumed products, as the air inlet is considerably below the outlet. This contamination of the air is one of the principal faults with the ordinary inverted burner, and many devices have been adopted for preventing it; but I have found that with many of them an escape of gas at or about the top of the burner will not ignite owing to the amount of oxygen-less air at that point. This proves that the ingoing air must be also more or less denuded of the oxygen, which I need not say is the portion of the air required to give life and heat to the flame.

The economy of gas in the use of the incandescent system is one point, but there is another of equal importance to consider, namely, the amount of air vitiated. The smaller the quantity of gas the less vitiated air (1 cub. ft. of average gas requires 5·5 cub. ft. of air to ensure its perfect combustion), so that this amount of air must be allowed for in the scheme of ventilation, beside the 16·66 cub. ft. per hour expired by each adult human being. This 16·66 cub. ft. air contains when expired 4 per cent. CO_2 (normal air only contains ·04 per cent.). This must be diluted 100 times, so that 1000 cub. ft. fresh air is required for each person; but allowing for organic exhalations, some 2000 cub. ft. are required per hour.

On the same basis, the gas requires per cubic foot consumed 1200 cub. ft. fresh air. From these figures the necessary ventilation can be calculated.

It might be mentioned that the use of a small flat-flame burner in a chimney will give admirable results as regards ventilation, as each cubic foot of gas so burned will cause 2400 cub. ft. of air per hour to pass through the chimney, at a speed of current of 200 ft. per minute. It need hardly be mentioned how necessary it is to carry ventilators above the level of the building, and not to have the outlet running horizontally.

As regards the heat evolved from gas burning, we may take it that with our gas here, each cubic foot will give us some 680 B.Th.U., representing 680 lb. water raised 1° F. As air has a specific heat of ·238, the 680 B.Th.U. would raise say 2620 lb. air the same extent. One lb. air equals 13·1 cub. ft., so that the 2620 lb. = 34,322 cub. ft. If then we divide this figure by the cubic contents of the room, we get the rise in degrees. Taking the room already referred to, namely, 1000 cub. ft., we get a rise = 34·3° F.

But for each cubic foot of gas burned we must raise the changing air say 1200 cub. ft. per hour, and for each person 2000 cub. ft., so that the actual rise is not nearly so great, as the ventilation must be arranged for at least two or three persons, and thus, on the latter assumption, we only get a rise of less than five degrees.

The question of governing the pressure, where incandescent burners are in use, is not generally understood. Many think that, because, in the past, governors on house or factory pipes were used for reducing the pressure to the greatest possible extent, that now, when the highest pressure is advantageous, the governor should be conspicuous by its absence. This is a mistaken idea, because the use of a governor is most beneficial, especially where, as is frequently the case, the pressure varies greatly between day or night. It is quite true that a high pressure gives a higher flame temperature; but if an incandescent burner, and especially an inverted one, be regulated so that the quantity of gas is correct when the pressure be at its lowest, then, when the pressure increases, the quantity will be too great, and in consequence the mantle become blackened, when the light emitted will be greatly reduced. Therefore such burners should be either regulated so as to be correct at the highest ordinary pressure, to prevent blackening, which will make them less efficient at the lower pressures, or a governor should be fixed which will keep the pressure constant at all times, but which should be regulated at the highest pressure which can be constantly maintained throughout the ordinary periods of lighting.

To compare the cost of gas lighting with electric lighting, the following figures showing the light of a number of candles burning for an hour for 1d. might be of interest :—

High-pressure incandescent gas	@ 3s.	gives for	1 hr.	1662	candles for a penny.
Low-pressure ,,	@ 3s.	,,	,,	695	
Flat flame (15 c.p.)	@ 3s.	,,	,,	83	
Electric incandescent lamps	@ 4d. per unit			68	
Electric "Osram" E lamps	@ 4d. ,,			200	

The objection to gas lighting as compared with electric has always been held, on account of having to apply a light by match or taper to the former, whereas the latter could be turned on at a switch from any distant point. Many patents have been taken out for obviating this, and perhaps the most simple arrangement has been the pneumatic distance lighter. A sliding valve, of very simple construction, at the burner is actuated by air pressure conveyed from a switch placed at any convenient point and connected to the valve by a very small tube, measuring less than $\frac{1}{8}$ in. in diameter. The switch consists of a plunger which serves to compress or exhaust the air in the tube and so push or pull the valve at the burner. A small pilot jet is, of course, always kept alight to ignite the gas.

The electric lighters are usually worked by means of a battery and coil, and the igniting spark produced by a vibrating make and break, small magnets in the base of the lamp serving to open and close the gas cock.

In the most recent, however, known as the "Telephos," the valve is worked by means of an electro-magnet, and at the same time the current passing through a platinum wire renders it red-hot, and so the gas is ignited. Provision is made for turning on the gas at the burner, and its ignition by a light in the ordinary way if required.

Davy first produced platinum black which absorbs or occludes as much as eight hundred times its own volume of oxygen, and is capable of glowing in a stream of hydrogen or coal-gas and air. This is owing to the condensation and impression of the hydrogen from the coal-gas and oxygen from the air, which becomes so active as to raise the temperature of the platinum to a red heat, but not to a sufficient extent as to ignite the gas. If now the pill of platinum black be attached to a very fine platinum wire, and they are held in contact with the outgoing gas and air, the platinum black becomes red-hot and warms the platinum wire, which then becomes white-hot and sets light to the gas almost instantly.

Various appliances have been invented for utilising this property of the platinum black and wire. One is the small pocket gas-lighter with which no doubt many of you are familiar. Another arrangement fixed the lighter at the top of the chimney of an upright burner, but this got quickly damaged by the constant heat. Other attempts have been made by fixing the lighter away from the heat of the flame, but at such a position as to make it ignite the stream of gas from a bye-pass tube. These have been more successful, and the latest development is the inclusion of the lighting agent among the threads of the inverted mantle, which, so far as can be at present seen, appears to be capable of lasting as long as the mantle itself.

Of recent times many successful methods of automatically lighting the street lamps of any district have been introduced. These may be divided into two sections, one where clockwork is used, and the other where an alteration in the pressure in the mains actuates the mechanism.

In the first section two systems have come largely into use. The Gunning controller is one in which the clockwork is arranged to open and close the valve, admitting the gas to the burner at any times for which it may be set, and which requires to be altered each week as the days lengthen or shorten. The Horstmann, on the other hand, is provided with two cams which automatically change the hour of lighting and extinguishing throughout the year according to a prearranged scale, and these controllers only require periodically winding.

In the other systems, the Alder & Mackay apparatus uses a small holder which, when the pressure is raised, rises and actuates the valve, and when the pressure is again raised it moves the valve a farther distance and closes it again. M'Kelvie & Rosie's apparatus is very ingenious and it also uses a holder, but has mercury cup valves: here also the second raising of the pressure shuts off the gas. The Hepburn system has two small holders which are raised by an excess of pressure above the normal maximum, and the gas is then able to pass direct to the burner. The pressure can then be lowered to the normal minimum, and the burners will remain alight. When it is desired to extinguish the gas, the pressure is reduced slightly below the normal minimum, and the passage is then closed and will remain closed even though the normal maximum pressure be put on the district.

We next come to those systems where power is used to raise the pressure of the gas. One of the first was the Keith system, where the pressure of the local water supply is used to increase the pressure of the gas up to 10 in. This increased pressure causes a greater rush of air at the side holes of the bunsen burner, and a better mixture of the gas and air, so that a greater heat is obtained. As it is the heat that is made use of to make the mantle white-hot, this increases the amount of light given off by the mantle, and the higher candle power of 30 candles per cubic foot of gas consumed is developed. The system has many advantages where large spaces (either indoor or outside) have to be well or cheaply lighted, but there is the extra expense at the outset of the compressing plant and also the continual expense for water, as 170 gals. per 1000 cub. ft. of gas consumed is required. The quantity, however, varies according to the pressure available. The advantage of such apparatus is that it starts or stops working when the gas is turned on or off in the ordinary way, and its speed is regulated in proportion to the gas consumed. Electrically-driven compressors are also used for this apparatus, when one horse-power will compress from 5000 to 10,000 cub. ft. of gas. For the higher pressures up to 5 lb. per square inch, although only 54 in. pressure of water is required for the new special inverted burner, the rotary type is necessary, which can be driven either by a belt of running shafting or by direct drive from gas-engine or electric motor. With this high pressure from 60 to 70 candle power per cubic foot of gas is obtained with the use of special inverted burners. These lamps are familiar, as they were used to a large extent at the Scottish National Exhibition held in this city last year, and they represent the highest duty yet obtained from coal-gas of ordinary qualities.

The Sale & Onslow system of high-pressure gas-lighting is peculiarly adapted for lighting up large interiors such as railway stations or workshops or for street lighting.

It consists essentially of—

1. A power-driven pressure raiser or blower which draws gas from the supply mains and delivers it at the required pressure into the high-pressure service mains.

2. A relief valve which can be set to act at any given pressure, whereby when the pressure rises, however slightly, above that required in the high-pressure service mains, the surplus gas passes back from these mains to the supply mains.

3. A back-pressure valve which remains closed when the blower is in action, but which allows gas to pass from the supply mains to the high-pressure service mains at the ordinary pressure when the blower is out of action.

A rotary forcing blower is used as pressure-raiser, which may be driven either direct from workshop shafting or by any suitable motor. It should be speeded to give rather more gas than required to feed the burners on the high-pressure mains, the excess being returned by the relief valve to the supply mains. It will readily be understood that the pressure in the high-pressure service mains is thus kept quite constant and unaffected by any fluctuations in pressure in the supply mains.

The special advantage claimed for the Sale & Onslow system of high-pressure gas-lighting is its extreme simplicity, nothing being required beyond the power-driven pressure raiser and a couple of very simple valves, which latter may be compounded into one double acting valve.

With this system pressures up to 50 in. and 60 in. (of water) may be used, giving a light of 40 candles per cubic foot of gas per hour. The smallest burners may be used—or, if it be desired to have specially powerful single lights, special burners (as described below) up to 1300 c.p. can be had.

Burners in sizes of	100 c.p.
" "	250–300 "
" "	500–650 "
" "	1000–1300 "

The light given has all the brilliancy of arc electric lighting without any of the disagreeable and trying flicker and variation inherent in that method of illumination. Workshops lit by it have an excellent diffused light, which, except in rare cases, renders unnecessary the individual lighting of machines or fitters' benches, and it is much cheaper than arc electric lighting, both as regards first cost and maintenance.

The reason this system gives such a good light is that it induces a good current of air and a thorough mixture in the burner. When there is surplus power to drive the fan, as in most workshops, the system proves very economical. It has been introduced into many of the shops at the Royal Arsenal, Woolwich, and in many cases displaced the electric light, there being some forty installations in use, these amounting to about 2,000,000 c.p. with an enormous saving.

The "Brown" system of high-pressure gas-lighting is probably one of the simplest forms of apparatus on the market for obtaining the high pressure for the modern system of gas-lighting. It is of very small compass, as a plant to deal with 75 cub. ft. of gas per hour and for compressing from 12 to 70 in. of water measures only 3 ft. wide, 1 ft. 6 in. deep, and 3 ft. 6 in. high. This would be large enough for most shops, and it would supply from seven to eight 300-candle power lamps, and cost only some £10. It consists of a double acting hydraulic motor mounted between two double acting gas compressors with a continuous spindle through the three. These are mounted above a storage or regulating cylinder. As the water used in the hydraulic motor does not come in contact with the gas, it is perfectly clean and pure and can be used for washing or any industrial purpose. The arrangement of the cylinders prevents any possibility of a dead centre at any point, and the apparatus adapts itself automatically to the quantity of gas being used, and immediately all burners are extinguished the machine comes to a dead stop.

For high-pressure lighting the cost of compressing the gas only amounts to from 2½ per cent. to 4 per cent. of the total cost of the gas consumed, which is very small when it is compared with the extra light obtained.

CHAPTER V

Distribution—Heating and power—Stoves: heating, cooking, trade—Calorific power—Ventilating power of gas—Carburetted water-gas—Blue water-gas—Mond gas—Power gas—Gas-engines—Acetylene gas—Petrol air gas.

WITH reference to the best method of obtaining the required radiant heat from a gas stove, the question of the filling is important. The stove with the iron frets, which at one time was fairly common, is still probably the best form of radiant heat supplier for the gas used, and is distinctly better than the ordinary fireclay ball fuel thrown indiscriminately upon the burners. It has long been known that the flame should have a free flow among such fuel and not be checked too rapidly or it might prevent proper combustion with the O of the air, and thus prevent the complete formation of the CO_2. In this way some of the CO might pass up the flue, and heat thereby be lost. The Welsbach Company some time since introduced a stove in which a number of fireclay tubes were fitted each above a bunsen jet. These tubes became red-hot and gave off the radiant heat. This proved superior in heating power to the ordinary arrangement of ball fuel, as before mentioned, but more recently this ball fuel has been made more regular in shape and of the required size, so that it can be arranged symmetrically and forms openwork channels above each burner, so that the flame has a free passage throughout. The balls of fuel surrounding the flame are thus in the hottest part of it, as it is at the point where the CO of the gas meets the O of the air and is converted into CO_2 that the highest temperature of the flame is found. These stoves so fitted come practically to the same efficiency as the iron fret fires. As the temperature rises the proportion of the heat radiated is much increased, a white heat giving off about fifteen times the radiant heat of a red heat. This leads us to the conclusion that we must adopt every means for the increasing of the flame temperature, so that the material in a stove shall be rendered very hot and thereby radiate as much of this heat as possible. Some bunsen burners make considerable noise, but this can be reduced if the burner nozzles are drilled out and not left cored as from the foundry.

While it has been recognised among burner makers that to get the most intense heat of flame, the nipple through which the gas issues must be of the proper size for the quantity of gas to be consumed, this has not been so thoroughly recognised as regards the gas stoves. When it is understood that if the nipple of a bunsen burner is suitable for 17-candle gas it requires reducing to three-quarters the diameter with 30-candle gas and to half the diameter with 60-candle gas, it will be seen that this is an important item in the making of gas-stove burners.

As regards the comparative costs of heating by gas stoves and by coal it may be stated that where the price of the gas per 1000 cub. ft. is less than 13 per cent. of that of a ton of coal, it will pay to use a gas stove. This is without allowing for the numerous advantages which the gas stove has over the coal grate.

While on this subject of cost, it may be mentioned that for cooking the price of gas per 1000 cub. ft. may be as much as 18 per cent. of that of a ton of coal, and yet it will cost less for cooking than a coal fire.

Roughly speaking, for each 100 cub. ft. capacity of room to be heated 1 cub. ft. of gas per hour will be required in the coldest weather.

In recent years it has been the endeavour of all stove makers to secure as wide as possible an angle of radiation from gas fires. This was carried out chiefly on the lines of having what has been known as the projecting fire. The cast-iron fret "ribs" or bars, in front of the "fuel," which in the earlier gas fires was flat, and flush with the grate-body of the fire, was made with a curve projecting from the front of the stove. While these of course do very well in a general way, they have not given the degree of radiant heat at the sides that was expected, and there is the further difficulty that currents of air are liable to catch the flames in such a way as to cause the fumes to come out farther than the canopy can deal with, and so get partly into the room. The aim of the experiments that have been made is to get the maximum of radiation without the drawbacks of a projecting fire, and this has been done by the use of the new type of ball "fuel," as already described.

This "fuel" is made in long lengths and can be used without the usual bars in front, and only requires one cross bar at the top to keep it in position; and besides the extra advantage in a directly forward direction, the side radiation is also largely increased, while the angle of radiation is wider than anything hitherto attained. At an angle of 50° with the face of the fire this amounts to 26 per cent. increase, and at 30° the same percentage of increase is also found. The average increase over the whole front was equal to 18·6 as compared with the 1907–8 pattern stove of the same make. It might be interesting to give some figures as to the comparative heats radiated at various angles from the face of this modern type of stove. If we take the heat radiated directly forward or at 90° from the face of the stove as 1·00 then at

10° we get ·32
20° „ ·56
30° „ ·71
40° „ ·84
50° „ ·94
60° we get ·98
70° „ 1·0
80° „ ·99
90° „ 1·0

The feeling of dryness of the air in rooms which are gas-heated is an objection to this form of heating which is held by many people, and the reason of it is not generally understood. When a coal fire is used, the quantity of air drawn up the chimney may be taken as 1500 cub. ft. per hour as compared with 250 cub. ft. by a gas fire giving off equal heat. To supply this air with the coal fire, air has to be drawn into the room through door and window crevices to a similar extent; and this comes in laden with the amount of moisture which its temperature will allow it to carry. Consequently the smaller quantity is quickly heated, and then is capable of carrying more moisture; and unless this is supplied will feel dry. Frequently bowls of water are seen in front of gas stoves, placed there, presumably, to supply the required amount of moisture; but these are most often put in such a position that any moisture given off by them is carried by the draught up the flue. Stove makers should supply some means of fitting such bowls so that the necessary heat may be obtained to vaporise the water without it passing away uselessly; and to ensure the maximum amount of ventilation the plate generally used to cover the ordinary fireplace should not fit the opening too closely. Better still, the flue may be contracted just below the level of the ceiling and a mica flap ventilator inserted as near the ceiling as possible.

As regards the presence of deleterious products in the combustion of gas in bunsen burners, it is found from an analysis of these, taken in the centre of the glowing fuel of a gas stove, that some 10 per cent. of CO exists; and should this, by means of a down draught, be forced into the atmosphere of the room before it can be completely consumed, its bad effect would be felt without any indication, as it has neither smell nor is the flame coloured.

The *Lancet* employed a number of scientific gentlemen to make tests of certain gas stoves; and the average of twenty-four stoves which they tested gave an analysis in the flues of 12 per cent. O, 84 per cent. N, 4 per cent. CO_2, which proves that under ordinary working conditions all CO has been combined with the proper proportion of O to form CO_2 before it reaches the flue, which latter gas, it need hardly be said, is innocuous, and the heat of such flue gases will remove from 20 to 30 per cent. of the heat given off by the stove in warming the chimney to ensure a satisfactory draught.

It should be remembered that the air of a room containing even as much as 60 volumes per 10,000 of CO_2 is not poisonous, but when the quantity rises to 300 per 10,000, then respiration becomes slightly deeper and more frequent.

Dr. Bonney says, regarding the use of gas stoves in bedrooms: "They are indispensable to the health of all but the most hardy. They are not one atom less healthy than coal fires, and a hundred times more convenient. Every one who is in any way delicate, especially on the chest, should have a gas fire in the bedroom."

While Dr. H. A. des Vœux, speaking at a discussion of the Society of Architects, said: "Gas fires are recommended in hospitals for consumption. The up-to-date gas fire is a healthy fire. With a coal fire you simply make unpurified gas, but with a gas fire you use purified gas. A gas fire only produces a stuffy atmosphere when the ventilation is defective; it is entirely a question of ventilation."

The advantages of the gas fire in the sick-room or nursery are very great. The temperature can be regulated to any desired amount and this temperature kept up constantly. Food can be prepared upon it at any time. It can be left without fear, and does not require "mending," which with a coal fire is always a noisy proceeding and likely to disturb the patient.

It must be remembered in comparing costs that immediately the heat is no longer required the fire can be turned out and no further expense incurred as with a coal fire, which must be left to die out. The gas fire has not to be lighted a long time beforehand so that the fire may have drawn up and the room be warmed. If a visitor calls, the tap can be turned on, the gas lighted, and the room is warm and comfortable in a few minutes.

In the earlier times of gas stoves, it was impossible to use them at a low pressure or to turn down the burners, as they were always given to lighting back. Nowadays, the burners are provided with a piece of gauze or a grating to prevent this, which acts on the principle of the Davy Safety Lamp. Some makers, however, arrange the burners so that every alternate one may be shut off, and thus the quantity of gas consumed can be halved after the room is warm. This is a patent. Other arrangements for the same purpose by other makers turn out so many of the jets at either end and leave the centre group alight, or in some cases each flame is produced by two D-shaped jets, one in front of the other, and the turning off of one tap shuts off one or other of the rows of jets, leaving the same number of flames but half the power.

For a gas stove to be satisfactory it is necessary that it should be considerably larger than is required to keep the room warm; this is because it is necessary to warm the walls and furniture before the feeling of warmth is obtained. In this country, we have never taken kindly to the placing of a stove well out into the room, although in Germany, Russia, and many other countries where intense cold obtains at times, the stoves are placed in the middle of the room, which is, of course, the best possible position. However, the ordinary gas stove can be placed more out into the room than is usually done, with good effect, and an addition to comfort can be obtained by fitting the regulating tap say 3 ft. above the floor, so as to save leaning down; and it might be mentioned that the gas is less likely to light back with a cock than with a screw-down valve. That the gas fire saves considerable labour in the household is certain, and while when used intermittently they cost less than a coal fire, they are certainly slightly dearer when used constantly. It must be understood that a gas fire will not cure a smoky chimney, as any down draught will cause the spent gases to enter the room. These spent gases, unlike those from coal fires, are not so easily detected, but they must be slight, or the air of the room would not seem to be dried, as a large proportion of the products of combustion are water vapour. Where it is desired to test the dryness of a room, the simplest plan is to moisten blotting-paper, cut it in two, and compare the time of drying of each piece, one in a gas-heated room and the other in a coal-heated room.

Professor Carpenter has laid down a rule that one B.Th.U. per hour is required for each square foot of glass or for each 4 sq. ft. of wall for each degree of temperature (F.) required between inside and outside air; but the rough-and-ready rule is that 1-in. width of fire is required for each 1-ft. width of room.

The condensing stove aims at the removal from the products of combustion of the water vapour, due to the combination of the H of the gas and the O of the air, and in the condenser all this water and the sulphur compounds will be trapped. It might surprise some to learn that a pint of water can be condensed from 30 ft. of gas. In these stoves, only the air necessary to burn the gas should be introduced, and the surface of the metal composing the chimneys, etc., must be sufficiently large to ensure the condensing of all the water made. The heat from these stoves is convected and not radiant, and therefore tends to heat the top of the room most. On this account they are very well suited for entrance halls and staircases. These flueless gas stoves are economical from a point of view of heat, but as increased ventilation is necessary when they are in use, this introduces so much cold air as to do away with the increased advantage.

It has been suggested that in place of closing up the coal fire grate completely with a sheet of iron, as is usual, a space might be left in same which could be varied in area up to 20 sq. in. so as to change the air of the room more frequently. A most important point in the fitting of the flues is to see that there are no sharp bends in same, and if possible to carry no part of the said flue horizontally. Everything should be done to induce a draught up the chimney.

A modern type of stove, which is admirable in workshops, factories, churches, public halls, staircases, etc., is of the pattern of the steam radiator, originally introduced from America. These are fitted with glass water gauges and automatic gas valves which keep the pressure inside these radiators at about 2½ lb., so that when the apartment is heated, and consequently less heat being absorbed from the stove, the pressure begins to mount up; but the effect of this rise is to close the gas valve, so that the temperature of the room is kept fairly even and the pressure in the stove constant. Similar radiators, in appearance, are also made in combination with open gas fires, the products from which are condensed. Such a fire gives a cheerful appearance, with some of the advantages of the radiator. Where the passing of the products of combustion into the atmosphere of the building heated would be harmful, as in greenhouses, schools, etc., and where the use of a light, as in motor garages, would be dangerous, the radiator can be connected up to an automatic gas-heated low-pressure boiler, which latter can be placed outside the building. These boilers can be fitted with an automatic valve, which, once the boiler is sufficiently heated to deliver water at a temperature of 180° F., will reduce the gas consumption to the minimum necessary for maintaining that temperature. The burners of such a boiler, of course, have to be arranged so that they can be turned very low without lighting back. The boilers can be made low in height, so that no stokehole is required. The radiator, however, should then be placed on small pedestals. In arranging for the fixing of all these steam radiators, the number of loops should be decided on according to the cubic space to be heated. The following gives the number of cubic feet of space a 39-in. double column and a 36-in. single column radiator will heat.

	Double Column, 39-in. per Loop.	Single Column, 36-in. per Loop.
Workshops, factories, and stores	760 cub. ft.	400 cub. ft.
Churches, public halls	600 ,,	350 ,,
Entrance halls, staircases, etc.	450 ,,	250 ,,
Offices, etc.	360 ,,	200 ,,
Sale shops	600 ,,	350 ,,
Schools	450 ,,	250 ,,

As has already been pointed out, the quality of any gas from an illuminating point of view is not a direct indication of the heating value, although a rich gas will also have higher heating value than a poor one, but not in direct proportion. From tests which I have made, I have drawn up a list of the average number of heat units which can be obtained from gases of various candle power. These, while differing slightly from Mr. Norton H. Humphrys', follow very much on the same lines. Like him, I find that there is a critical point about 21-candle power.

15 c.p. gas	600 B.Th.U. per cub. ft.
16 ,,	640 ,, ,,
17 ,,	680 ,, ,,
18 ,,	720 ,, ,,
19 ,,	760 ,, ,,
20 ,,	790 ,, ,,
22 ,,	840 ,, ,,
24 ,,	880 ,, ,,
25 ,,	900 ,, ,,
30 ,,	1000 ,, ,,

While these figures show the maximum heating power obtainable on the various gases, only a small portion of these can be utilised in most of the heating and cooking apparatus now employed. Probably the best are the Rapid bath heaters, which lose only some 9 per cent., or, in other words, have an efficiency of 91 per cent., while the best boiling burners will only give some 45 per cent., and for the small ring burners possibly not much more than 22 per cent. of the original heating value of the gas is utilised. I have referred in a lecture given elsewhere to the necessity of arranging the flues from a gas cooking stove (such flues being always advisable), not only to carry off the products of combustion from the burners, but also the smoke, steam, and smells from the cooking. It is far better to connect such a flue to the flue of the main kitchen range unless a special flue, carried to the same height, has been provided; otherwise a down draught may occur through the gas cooking stove flue owing to the superior pull of the coal fire chimney.

In these days of scientific cookery the addition of a thermometer to the fittings of a gas-heated cooking oven, preferably of the dial type with the bulb inside the oven and the scale outside to facilitate easy reading, is an advantage, enabling the cook to get the oven at the best temperature for the cooking in hand, and would save both as regards the gas and the food being cooked. Possibly many of our cooks do not know what are the correct temperatures for various cookery purposes. These are as follows:—

For roasting pork	320° F.
„ veal	320° F.
„ pastry	320° F.
Puff pastry	340° F.
Roasting beef	310° F.
„ mutton	300° F.
Meat pies	290° F.

The fact that there are no deleterious fumes given off from the gas when it is burned in the oven is now generally known, as the food when being cooked is constantly giving off steam, no taint of the gas products can be absorbed by it; but efficient ventilation of the oven should always be allowed for, so that such moisture, etc., driven off during cooking may be readily carried away. The objectionable smell occasionally given off when cooking, is sometimes greatly increased by the failure to keep the gas stove properly clean and to remove all grease from it so that it cannot burn, as it is this which makes the most smell.

The use of enamel linings and facings has led to greater cleanliness, but that "Cleanliness is next to godliness" is true, cannot be too strongly enforced where gas stoves are in question.

Another modern addition is the jacketing of the oven with some non-conducting composition, which has added considerably to the efficiency of the gas cooker; and this should be insisted on where economy of gas is desired.

If the oven be heated externally, it will require one cubic foot of gas to raise the oven 125° F. for each square foot of exposed surface. If the burner, however, is inside, the same quantity of gas will raise the temperature to 250° F.; and if the oven be jacketed with say 1 in. slag wool, the temperature will be raised 430° F. In all cases where the gas jets are at the bottom, which is the usual position for them, the shelves should be perforated, or of grid form, so that the heat can pass up through them; otherwise the temperature below and above the shelving will be very different.

To get the best results from a gas oven, it should be fully heated for say 10 to 15 minutes before inserting the food and then the gas reduced to about one-half, when the cooking will proceed to the best possible advantage. The oven should be washed out with hot water and soda after use, more particularly when roasting has been done.

As regards the quantity of gas required for cooking, it may be taken as an average that 1 lb. of meat requires 1 cub. ft. of gas when joints of some size are in question; but if the meat is to be grilled, 4 cub. ft. will be required per 1 lb.; and when arranging the gas supply an allowance of 5 cub. ft. per hour for each person to be supplied will be sufficient with a minimum size of connections of ½-in. bore, with all bends, tees, and cocks with full way. So many of the ordinary cocks are much restricted in the passage way, and are not suitable for gas supply to cookers. Where common paint, varnish, or ordinary enamel has been used on a stove, it will take a long time before the smell which it will give off when heated will wear away; hence only indestructible enamel should be used, and for household embellishment only the ordinary black lead employed. It should not be necessary to point out, but it is certainly advisable, that the burners should be turned off immediately their work is done, so that due economy of gas is obtained; and with such care it will be found that gas is not dearer than the usual coal fire. It is the careless use of the familiar friend gas that has given it its bad name for expensiveness.

Some figures as regards the quantity of gas required for heating water might be of interest; thus, where water is required for a bath, each gallon can be heated with 1 cub. ft. If the water is required for washing or scullery purposes, then 2 cub. ft. will be required per gallon; but where the water has to be boiled, as in the making of tea, etc., then 5 cub. ft. per gallon are necessary. This of course is on account of the rate at which the heat is transferred from the gas to the water.

Pans or kettles used over boiling rings should be flat and as broad as possible, so that the whole of the flame is confined to the bottom of the vessel. In this way gas is saved, because the heat is all transferred to the water.

While upon the question of boiling water, it might be well to remind you it is best to use for such purpose bright copper kettles, as copper transmits 2·4 times the heat that cast-iron does, and also that a bright surface loses about 25 per cent. less heat than a dull black one.

Where a hot-water system has not been fitted into a house, or where gas is used entirely for heating and cooking purposes, high-pressure boilers heated by gas can be installed, supplying hot water to baths, lavatories, sculleries, etc. These high-pressure boilers are also fitted with an automatic gear, which closes down the gas pressure whenever the temperature of the water arrives at a predetermined amount, and then keeps the gas at the necessary quantity to keep up this temperature. These regulators are worked much upon the lines of the aneroid metallic expanding boxes.

These gas-heated boilers remove the objection to the gas cooker which is held by certain people, because of the trouble about getting hot water if they put out of use their coal range, with its connecting hot-water arrangements. These boilers can be connected up to the existing hot-water supply system throughout the building, and form in themselves the hot-water tanks, so that the existing tank is bye-passed.

There is another type of apparatus in the market intended for the same purpose, which is much smaller and costs less to buy in the first instance; these are of the "circulator" type. In using them the existing hot-water tank is retained. The circulator has two burners under it, a large and a small: both burners are lit to begin with, and once the whole of the water throughout the circulation is heated to the required point, some one is supposed to turn out the larger burner, leaving the small one alight to maintain the temperature. One objection to this system is that the "circulator" arrangement involves the whole of the water in the circulation going round and round, getting gradually cooled as it reaches the extremities of the circulation, and coming back to be reheated again in the apparatus, all this continuous cooling and reheating going on whether hot water is being drawn or not. The other objection is that any apparatus for a purpose of this kind is extravagant, and therefore not to be recommended unless it has an automatic arrangement for cutting down the gas and turning it up from time to time as hot water is drawn off. With circulator apparatus, even if a servant remembers to turn out the big burner somewhere about the right time, it is a thousand to one that the people who draw off hot water will never trouble themselves to relight the large burner; so that either too much gas will have burned to get water at a decent temperature, or else, with a small burner only, the temperature will not be high enough, and in any case gas is wasted in the reheating process.

With the gas-heated boiler described all this circulating process is avoided, but there is the slight inconvenience (which I am afraid obtains with most ordinary coal range systems) that a certain amount of cold water must be run off before the hot comes.

Rapid bath heaters or geysers are dangerous when placed in small rooms without a flue pipe to discharge the great amount of the products of combustion, owing to the large quantity of gas they consume, although this consumption only lasts for a short time. The flue pipe should not be reduced in diameter throughout its length, and the covering cowl should be twice the area of the vent pipe. Cast-iron vent pipes are not satisfactory. If possible, the pipe should be connected to the flue of a chimney of a fireplace on the same floor as the geyser, or it may be carried through a false roof overhead, then covered with a cowl. The burners on these geysers should not be lighted underneath the water pipes, as in this way explosions may occur. The burners therefore should be made to swing out when they can be lighted outside, or a flash lighter attached to the tap. An important point is, of course, to ensure that the water is turned on before the gas is lighted.

In many towns gas used for heating and cooking is charged for at a lower rate than that for lighting, owing to the fact that such gas is used principally during the daylight hours, when the mains would otherwise be nearly idle, and so bring the day and night load more closely alike. The difficulty of such differential charging has been the necessity of two sets of pipes and two meters in the house, and this has been expensive. Mr. Marsh has introduced recently what he has called a "discount meter," which is about the size of a breakfast cup, and which can be connected up near the stove or range, and will then indicate the quantity of gas consumed by the apparatus. This meter is not perhaps quite so accurate as the ordinary and larger-sized meters are, but is sufficiently correct to permit of their use, especially seeing that the gas is already measured by the ordinary meter; and the indication of the discount meter, as its name implies, has to be deducted from those of the larger and charged at the lower rate, the balance being charged at the ordinary price.

A contrivance which is very widely used is the gas iron heater—*i.e.*, a conical sheet-iron appliance with flat irons resting against it. It is for placing on the top of an ordinary gas cooker hot plate immediately above one of the burners, and so utilising the cooker as an ironing stove. Other forms of iron heaters require a pipe to be connected up to the iron. At first these are a little difficult to handle, but their use is quickly learnt, and they have the advantage of being always hot.

As regards the industrial use of gas, among the many uses to which the heating power has been applied are the following: washing-machines; heating flat-irons; externally and internally drying and airing clothes; heating bottling stores and brewers' cellars; bottle washing; heating japanners' stoves; drying founders' cores; heating liquids; drying paper impressions for stereotypers; hot-pressing hosiery; crumpet baking; working up plastic masses; heating bookfinishers' tools; typefounders' machines; bullet moulding; stereotype metal melting; type metal melting; solder making; lead melting; concentration and distillation of acids; hardening spindles of cotton machinery; making round and flat spring wire; tempering steel articles; reducing samples of refractory ores; testing the comparative fusibility of samples of firebricks, alloys, etc.; brazing bandsaws and steel instruments; heating brands for stamping wooden boxes; heating hollow calender rollers; heating bootfinishers' tools; wire-cable making; bright wire hardening; welding lead; heating material for printers' rollers; drying lithographic printers' stones; heating plates for pottery printing; enamelling on metal; heating muffle furnaces; toasting tobaccos; conditioning cigars; polishing sealing-wax sticks; heating vats containing caustic liquors and chemicals; heating confectioners' ovens; drying bacon, glue, and gummed papers; coffee roasting; heating soldering-bolts, etc.; and for many purposes in experimental and chemical laboratories.

Passing to other methods of making gas, we will first refer to carburetted water-gas. The plan used is, to pass superheated or dry steam through red-hot fuel, when the oxygen combines with the carbon, and CO is formed, the hydrogen passing off alone; consequently, water-gas, theoretically, is a mixture of CO and H; but these, *per se*, have no illuminating power, although they are capable of giving out a considerable amount of heat when ignited; so, for the purposes of lighting, they have to be carburetted, or, in other words, loaded with hydrocarbons, which, carried forward by the diluent gases to the burners, can be made to give up their light where required.

The theoretical manufacture of water-gas may be expressed by the following:—

$$2H_2O + C = 2H_2 + CO_2$$
$$2H_2 + CO_2 + C = 2H_2 + 2CO.$$

In other words, the steam combines with the carbon to form hydrogen and carbon dioxide; this meeting a further atom of carbon, becomes hydrogen and carbon monoxide.

Practically CO_2 is always present at the outlet of the condenser to the extent of some 3 per cent.

These, then, are the fundamental principles underlying the manufacture of carburetted water-gas.

The temperature at which steam is most ready to decompose is about 1000° C.

In the manufacture of producer-gas, or what might more properly be called a mixture of water-gas and producer-gas, such as is made in the Dowson apparatus, superheated steam and air pass through a mass of incandescent fuel; the steam is decomposed, while the air supports combustion, making in the same way as in water-gas, pure and simple, first CO_2, but, meeting the rest of the hot fuel, this is reduced to CO. In this apparatus, which is only used for the purpose of working gas-engines, anthracite coal is used, about 10 lb. of which is required for each 1000 cub. ft. of gas made; but, of course, besides this there must be added some 2 lb. of fuel, usually coke, for the purpose of heating the boiler for the preparation of the steam.

In a carburetted water-gas plant, coke is placed in the generator and heated up to redness, and further heat obtained by the use of an air blast. The generator consists of a wrought-iron cylinder lined with firebricks, the bottom being brought to a small area so as to permit of the easy introduction of the blast and steam. An opening is provided at the top for the introduction of the coke, from specially constructed wagons, which opening can be closed by a gas-tight door during the making of the gas. If, then, we imagine that the fuel is now heated up, we shall see that the only outlet for the products of combustion is through the carburettor and the superheater, and thence through the flue to the open air. During the passage through these pieces of apparatus, a large proportion of the heat will be given off to the checker brickwork with which they are lined; and when the whole plant is in working order and the blast is in use, only a little more than sufficient air is admitted to the generator to convert the carbon in the fuel into CO, the CO_2 formed serving to keep the fuel burning. This CO then passes to the carburettor, when a second quantity of air is forced in by the blast, so that a further portion of the CO is converted to CO_2 in the latter vessel, with the natural evolution of heat among the brickwork, a third portion of air being sent into the superheater to combine with the remaining CO, and thus again form CO_2, so that the gaseous fuel made by the generator is utilised to give the proper heat, a cherry red, to the remaining piece of apparatus. All now being heated, the air blasts are turned off and steam admitted at the generator, and in passing through, the fuel is separated into CO and H; these then meet the oil, which is sprayed in at the top of the carburettor in such a way that it covers the area of the top layers of checker bricks, having been already heated by the passage of the warm gas around the pipes through which the oil finds its way from the tanks. Pumps are used to force it in. The combined gases now pass among the heated bricks and are there permanently fixed, the superheater providing a lengthy contact, so that the oil is thoroughly cracked and converted into gases. The gas now passes through a seal-pot, washers, and condensers before being sent through the purifiers to the meters and gasholders, where it will be stored ready for distribution to the consumer as required. After some five minutes, the passage of the steam through the fuel will reduce the temperature of the latter; it is then shut off, as is also the oil, and the blast again forced into the three vessels so as to keep the heat in them up to the required standard, the usual time for this being some five minutes also, the exact time depending largely on the nature of the fuel. The plant is, therefore, alternately making gas and heating up again. The producer-gas, which is made during the heating-up period, is a combustible gas, and has a heating value of about one-eighth that of 16-candle gas; but the major portion of this heat is utilised for the purpose of heating the carburettor and superheater checker work. Fresh supplies of fuel are required in the generator about every three-quarters of an hour. As to the quantities of fuel necessary for the manufacture of this gas, and into the number of heat units liberated and absorbed at different parts of the apparatus, it is perhaps hardly necessary for us at this moment to inquire. The analysis, however, of the gas itself may be interesting, and the following, which is that given by the Engineer of the Belfast Gas Works, where this plant has been in operation for some time, may be taken as a fair average:—

Unsaturated hydrocarbons	10·7 per cent.
CO	31·9 „
Saturated hydrocarbons	16·2 „
H	33·7 „
N	7·5 „

The sulphur compounds, which require so much purification to satisfy the requirements of the London Gas Referees, do not with this process exceed 10 grains per 100 cub. ft., while the sulphuretted hydrogen in the crude gas is only about ·2 per cent.; the CO_2 in the crude gas equals 3·5 per cent.; but these two latter impurities are, of course, easily removed by the ordinary process of gas purification, by lime and oxide. Of the labour necessary for making a given quantity of coal-gas, only about one-half is required with carburetted water-gas, and this of an even less mechanical character. It is probably more economical to make a gas of 26-candle power than of any other, while the enriching value of such a gas is probably some 20 per cent. more than its nominal value, as is the case with most oil-enriching processes.

The oil which is most generally used in Great Britain is Russian solar distillate, which has a specific gravity of about ·875 and a flashing point of 170° to 200° F. Technically, no CO_2 should be present in the gases issuing from the generator, but practically this amounts to some 3 or 4 per cent., and is principally made during the end of the run, probably owing to the cooling of the bed of fuel by the incoming steam. To manufacture 1000 cub. ft. of gas about 45 lb. of fuel are required, while some 5·46 lb. of oil will be needed to make a gas of about 25-candle power.

For the purpose of obtaining an air blast in the generator, which, like that in the smith's fire, is used for readily kindling the fuel, and is required to be of a pressure of about 12 to 15 in. of water, centrifugal fans or blowers are used, worked by steam-engines running at considerable speed, generally about 2000 revolutions per minute. The blast mains are usually made of galvanised iron, of about No. 18 B.W.G., so that should there be any leakage of gas through the blast valves at the carburettor or superheater, and an explosive mixture gather in the blast main, which is at the moment not under pressure, on the approach of a light from any source, the mixture would be exploded, but little damage will be done, as the thinness of the blast pipes will cause them to readily split and allow of the expansion of the gases formerly in the tube. The oil, which is heated by the outgoing gas from the superheater, is injected by means of pumps into the carburettor, and is there sent among the checker bricks practically in the form of vapour.

In the starting of the water-gas plant there is always some chance of a slight explosion, which, however, is not likely to do any great damage if carefully looked after, and one of the most troublesome things to the gas manager where this plant is in use is the carelessness of the workmen, who, from long acquaintance with the apparatus, are somewhat inclined to treat it too lightly; and it is of sufficient importance when lighting up the plant at the first, and also whenever it has been allowed to run quite cold, that the manager should consider it his duty to attend very closely to the filling of the generator with fuel, and the looking after of the outlet and fuel-filling door, or explosions may occur which will possibly, at the least, render the apparatus useless without repair. The steam used is usually worked under a pressure of at least 130 lb. per square inch, and it may be here mentioned that steam at this pressure is practically dry, or, in other words, of a similar nature to what is commonly known as superheated steam. In most works the Babcock-Wilcox tubular boiler is used for the purpose of raising the steam. When the mixing of rich gases is made with poor ones, as is often done in England, where 16-candle gas is supplied and water-gas is made, the mixing should be done as early in the process of manufacture as possible. The purity of carburetted gas is such that with the purified gas, as sent out into the district, the total sulphur will not exceed 5 grains per 100 cub. ft., while the Metropolitan Gas Referees permit as high a quantity as 20 grains in summer and 17 grains in winter. It may be mentioned that they have stated that coal-gas never contains less than 10 grains. The making of gas of any required candle power is a very simple matter, the mere opening of a valve causing an increase in the quantity of oil injected, and consequent increase in the hydrocarbons in the gas; this having naturally an improved effect upon the illuminating power. In coal-gas, the percentage of marsh gas or methane is 35 to 40 per cent., with only some 5 to 7 per cent. of CO; while in carburetted water-gas the marsh gas is reduced to 20 per cent. while the CO is increased to 25 to 30 per cent. Above 22-candle power methane is more harmful in reducing the illuminating power than either CO or H, but below that it has not such a deleterious effect. Therefore, the fact that there is only half the methane in the gas supplied is an advantage at high illuminating powers, as is also the increased quantity of CO. All oil gases, or those rich in hydrocarbons, require a diluent in some form or another, to enable them to be satisfactorily consumed in the ordinary household burners, and the question of which diluent is the least harmful has been a matter of study for many years. Dr. P. F. Frankland determined the effect of various gases of little or no illuminating power of themselves upon ethylene, the candle power of which, *per se*, is 68·5 when consumed at the rate of 5 cub. ft. per hour, and the above remarks are made upon the results of his researches.

The great advantages of water-gas are, that it can be rapidly made and the plant quickly got to work, and that coke is used which may have otherwise to be sent abroad at low rates—the coke required for 3000 cub. ft. of carburetted water-gas being obtainable from that coming from the manufacture of only 1000 cub. ft. of coal-gas. It would seem, therefore, that if only one-fourth of the total gas made were coal-gas, all the coke made from this would be required for the other three-fourths of carburetted water-gas, and a greater proportion of the latter would necessitate the use of anthracite or the purchase of coke elsewhere. The calorific power of water-gas carburetted is perhaps some 10 per cent. less than that of coal-gas, say 600 heat units as against 670, while the size of flame given by it is smaller and of a lower durability than coal-gas of an equal quality.

The usual complaints against water-gas are that it has no odour, and that it is heavier than the ordinary atmospheric air. Neither of these, however, is in reality a correct statement. Water-gas alone, there is no doubt, is dangerous on account of the lack of any distinguishing odour, but this is entirely obviated by the carburetting or addition of oil vapour. The water-gas in the condition in which it is sent out to the consumer in this country, when it is required for the purposes of illumination, is heavily charged with hydrocarbons, obtained from the use of Russian petroleum, which gives it a distinctly stronger smell than is obtainable from coal-gas, while its specific gravity is about ·6, compared with the air at 1.

Blue water-gas, as it is termed, as it only gives a blue flame, is perhaps best made by the Dellwik-Fleischer system, where the air supply is most carefully adjusted, and the level of the incandescent fuel kept constant; then producer-gas is non-existent, and the products of the blow consist merely of the ordinary non-combustible products of complete combustion, namely, CO_2 and N. The result being that double the quantity of water-gas can be made per lb. of fuel, as compared with the carburetted water-gas plants, where some of the heat has to be used for gasifying and fixing the oils. The extra heat generated in the "Blue" plant minimises the period of blowing, and enables runs, or times of steaming, to be continued for longer periods than has been possible before. There is a very low percentage of CO_2 in this gas owing to the careful regulation of the steam into small quantities in place of large volumes—such water-gas has a calorific value of say 240 B.Th.U. per cubic foot.

The Mond system of water-gas making utilises a much larger quantity of superheated steam than is usually allowed for, and in this way the ammonia is not decomposed. The process is regenerative, when the heat of the gas made warms the incoming air and also dries the steam. The gas is first washed in an ordinary scrubber and then passed to an acid, tower in which it meets the 4 per cent. free acid which removes all final traces of alkali. For each ton of fuel placed in the producer, 3 tons of air and 2½ tons of steam have to be driven in. Of this steam 1½ tons is provided by the exhaust from various engines and pumps, while 1 ton comes from the regenerative system above mentioned. In this way some 4½ tons of gas can be obtained from a ton of coal, or say 160,000 cub. ft. Including 5½ tons of coal which is used in the making, it takes 28·5 tons of coal to obtain 1 ton of sulphate of ammonia by this process. The composition is as follows:—

H_2	24·8 per cent.
CH_4	2·3 "
CO	13·2 "
CO_2	12·9 "
N_2	46·8 "
Calorific value	154·6 B.Th.U. per cubic foot.
Combustible gas	40·3 per cent.

Power gases are generally those specially made from slack or anthracite, and are of low calorific power. The first was probably the Dowson Gas, named after its inventor, and consists of producer and water gas mixed. The plant required is a boiler for generating steam, a generator for anthracite or coke, an hydraulic seal, a coke scrubber, a sawdust scrubber, and a gasholder with governing gear to stop the making of gas when the holder is full. The process consists in the passing of superheated steam and air into the generator, which is filled with the incandescent fuel, when the O combines with the C, making

CO_2; then this CO_2 takes up another portion of C and becomes CO, while the O used to keep the fuel hot makes CO_2 and N. The analysis of such gas is as follows:—

CO_2	6·3	per cent.	by volume.
CO	23·8	„	„
CH_4 (marsh gas) . . .	1·3	„	„
H_2	19·8	„	„
N_2	48·8	„	„

1 lb. of anthracite makes 80·9 cub. ft. of this gas of 164 B.Th.U. per cubic foot, but to this must be added 0·18 lb. coke for the boiler. It therefore has only from one-fourth to one-fifth the explosive force of coal-gas.

There is no doubt that the gas main forms one of the cheapest forms of distribution of power, as the capital cost is lower and the loss in distribution much less than with electricity. The higher the calorific value of the gas the smaller the mains that will be required for any given power, so that it would appear that the richer coal-gas would be cheaper to distribute than the lower-powered producer and mixed producer and water gases. With these latter from 1½ to 2 of air have to be admitted with the gas when it is taken into the cylinder of the gas-engine, while with coal-gas about ten times the quantity of air to one of the gas can be used. It is the calorific value in the first place which we have to compare when using gases for power purposes, but there is a further point of much importance, namely, the proportions of the various constituents of the gas, as a larger proportion of some, such as CO, will allow of higher compression than others, while H will only permit of comparatively moderate compression without pre-igniting. It should be remembered that it is not the percentage of these gases in the original gas as manufactured, but their proportion of the mixture in the cylinder of the engine; so that although the proportion of H in suction gas is only 18 per cent. as compared with 53 per cent. in coal-gas, the proportion in the cylinder will be 12 per cent. with the former gas and 5·3 per cent. with the coal-gas. Thus with suction gas the compression must be reduced, and the consequent power of the engine is also reduced by 20 to 25 per cent. The higher the compression in a gas-engine the higher the explosive pressure, hence the advantage of high compressions. When the air and gas of any nature are mixed in the cylinder, the mixture contains about the same heat capacity—namely, 66 to 74 B.Th.U. as the proportion of air is varied.

The action of the gas-engine worked on the Otto cycle is pretty generally understood, so it need only be shortly referred to here. The gas and air are sucked into the single-ended cylinder, as the piston moves outwards, through the inlet valves, which stand open; the explosive mixture is then compressed, as the piston returns, in the head of the cylinder, up to some 80 lb. on the square inch, all valves being closed. On the completion of the compression stroke a spark or red-hot tube ignites the gases, an explosion takes place and drives the piston outwards, imparting momentum to the flywheel, which carries out the remainder of the cycle. The next movement inwards of the piston drives out the burnt gases through a third valve, called the exhaust, and leaves the cylinder ready for another charge. Owing to the heat of the explosions and their frequency, the cylinder soon becomes hot; but this is prevented from becoming excessive by water jacketing and by the circulation of water through same.

The question of the use of coal or producer gas, the latter either produced in a pressure or suction plant, is a vexed one. The former has decided advantages in that its composition and heat value is practically constant and the supply very regular; any sudden call upon the engine is responded to with a sufficient quantity of gas to work it; there are no stand-by losses, and it is always ready to start: whereas with the other gases there is always time lost in starting—in fact, most suction engines are fitted with a supply of coal-gas for starting purposes, or much time is lost in commencing working; and in many works the engine is kept running light during meal hours, so as to be ready to start at once on the resumption of work. There is no doubt that there is economy in the use of producer-gas over coal-gas for large engines, but for small powers the trouble of the making of the gas, and the necessity of having a man almost constantly in attendance on a suction plant, about balance the cost where gas is supplied at at all a reasonable price for power purposes. The Commercial Gas Company in London, who supply a million cubic feet of coal-gas per day for power purposes, make the following discounts from their standard price of 2s. 6d. per 1000 cub. ft. where the accounts exceed

£100 per annum				10	per cent.
£100 and not		£150	per annum	12½	„
£150	„	£200	„	15	„
£200	„	£250	„	17½	„
£250			„	20	„

The suction plant relies on the draw of the engine to pull through it the air required for combustion, etc., and consists of a producer made of a cast-iron case lined with firebrick and having a water chamber on top which is heated by some of the waste heat of the producer. The air, before it passes into the bottom of the grate of the producer, is drawn over the heated water, and steam is thus brought in with it, to be gasified in passing through the red-hot fuel, which requires to be anthracite, as coke contains too much tar, and without considerable purification the cylinder is then dirtied and the magneto-ignition points require constant cleaning. The only purification such gas gets is washing in a coke-filled scrubber.

An average analysis of suction producer-gas gives

H	17·6	per cent.	= 57·41	B.Th.U.
CH_4	1·6	„	= 16·38	„
CO	18·6	„	= 60·17	„
N	54·8	„	133·96	
CO_2	7·4	„		
	100·0			

I fear many of the suction plants being installed will not last very long as, owing to the competition among makers, the price is cut very fine, and the apparatus is made as cheap as possible. Those who are contemplating the introduction of such plants would be well advised to consult experts before deciding, as the cheapest in first cost will frequently prove the dearest in the long-run.

Acetylene gas, which is of a very high illuminating power, is obtained from calcium carbide (CaC_2). This substance results from a mixture of lime and coal or coke dust, which are fused together in an electric furnace, the calcium and the carbon alone remaining. The acetylene gas (C_2H_2) is formed according to the following equation :—

$$CaC_2 + H_2O = C_2H_2 + CaO.$$

In other words, the carbide is combined with water so that the hydrogen is decomposed and combines with the carbon, forming the acetylene gas and leaving slaked lime as a residue. Calcium carbide (CaC_2) is a compound of 62·5 per cent. calcium and 37·5 per cent. carbon; and if perfectly pure, 100 lb. of carbide and the necessary quantity of water should yield 40·62 lb. acetylene and 115·62 lb. slaked lime or 5·9 cub. ft. of acetylene gas per lb. of carbide. This gas has a specific gravity of 0·91 and an illuminating power of 250 candles for each 5 cub. ft. At 21½ atmospheres and at a temperature of 32° F. the gas is condensed and liquefied. 6·35 cub. ft. of acetylene gas are required for one horse-power. When used for enrichment of coal-gas, unlike other rich hydrocarbons, it does not show the same illuminating value as when burned alone, whereas with most rich gases the enrichment value is some 50 per cent. above its own illuminating power.

A system of lighting which seems likely to come into use in country houses beyond the reach of gas mains, is that wherein a large quantity of air is mixed with a very small quantity of the vapour of petrol, one gallon of petrol liquid serving to carburet 1000 cub. ft. of air. This gas would only burn in special burners; and if the gas escaped from a hole in the pipe, it could not be lighted, but the match would be blown out. The gas is practically non-explosive, as the proportion of petrol to air in the gas is almost below the explosion point; and, when the gas is mixed with the air of any room, it is then impossible for an explosive mixture to be obtained. All the air required for the combustion is supplied with the gas, so that none of the oxygen in the room is consumed, as is the case with ordinary gas. The gas has only about one-fourth the heating power of coal-gas, and consequently, to obtain the same amount of light with the Welsbach mantle, about four times the quantity has to be used. This gas can be used in stoves and cookers when slight alterations to these have been made.

In closing this course of lectures I am deeply conscious of many points having been left unmentioned, but the subject is such a large one that it was quite impossible to include but a tithe of what one could have wished; the necessity also of providing a fare which would be acceptable to those engaged in gas making and distribution, as well as to the other members of the Society and the public, has made the matter a still more difficult one. I have to thank you for your attendance and attention, and trust that the course of lectures has been of some interest to you.

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